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Report of the Seventh Commonwealth Entomological Conference

6th - 15th July
1960

LONDON
COMMONWEALTH INSTITUTE OF ENTOMOLOGY
56 QUEEN'S GATE S.W.7

DECEMBER 1960

PRICE 50s.

Commonwealth Agricultural Bureaux

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London, 1960.

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CONTENTS

PAGE

Report of the Seventh Commonwealth Entomological Conference, 6th–15th July, 1960 1

Conclusions and Resolutions 9

Appendix I. Memorandum on the Work of the Commonwealth Institute of Entomology from 1st April, 1954 to 31st March, 1960 12

Appendix II. Memorandum on the Organisation and Work of the Commonwealth Institute of Biological Control 20

Appendix III. Proceedings of Committees 28

Appendix IV. Proceedings of Open Meetings 34

Appendix V. Reviews of Work in Economic Entomology in the Commonwealth, 1954–1959 196

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REPORT
OF THE
Seventh Commonwealth Entomological Conference

6th - 15th July, 1960

Calling of the Conference

The Sixth Commonwealth Entomological Conference, at its final meeting, passed the following resolution:—

> "The Conference re-affirms the value of periodical meetings of entomologists drawn from as many countries of the Commonwealth as possible and recommends that steps be taken in due course for a Seventh Commonwealth Entomological Conference to be held in 1959, of which long notice should be given to enable the necessary arrangements to be made, at a place to be decided by the Executive Council of the Commonwealth Agricultural Bureaux."

For the convenience of overseas entomologists it was considered preferable to convene the Conference for 1960, so as to precede the XIth International Congress of Entomology to be held in Vienna in August, and also the Commonwealth Agricultural Bureaux Review Conference, arranged for August–September 1960. Accordingly invitations were conveyed to the Governments of the Commonwealth countries in May 1958 to send delegates to a Conference to be held in London from 6th to 15th July, 1960.

List of Delegates and Observers

The following official delegates attended:—

Aden.
    Mr. J. H. Proctor.

Australia.
    Mr. F. Wilson.

Barbados.
    Mr. J. R. Metcalfe.

Canada.
    Dr. A. P. Arnason.
    Dr. N. D. Holmes.

Colonial Office.
    Dr. R. A. E. Galley.
    Mr. W. V. Harris.
    Mr. D. Rhind, O.B.E.
    Prof. O. W. Richards, F.R.S.
    Mr. G. M. Roddan, C.M.G.

Federation of Malaya.
    Enche Ahmad Yunus.
    Mr. J. D. de Silva.

Ghana.
    Mr. K. B. Armstrong (West African Cacao Research Institute).
    Mr. G. K. A. Buahin.
    Mr. J. Forsyth.
    Dr. C. G. Johnson (West African Cacao Research Institute).
    Dr. H. Roberts (West African Timber Borer Research Unit).
    Mr. J. Rawnsley (Ghana Cocoa Marketing Board).

India.
    Dr. M. L. Roonwal.

Ireland.
    Mr. E. McMahon.

Jamaica.
    Mr. G. Stell.

Kenya.
    Mr. J. F. Graham.
    Mr. T. Jones (East African Agricultural and Forestry Research Organization).
    Mr. A. R. Melville.

Mauritius.
    Mr. J. R. Williams.

New Zealand.
    Dr. W. Cottier.

Nigeria.
    Mr. P. H. Giles.
    Mr. A. M. Jordan (West African Institute for Trypanosomiasis Research).
    Mr. F. A. Squire.

Northern Rhodesia.
    Mr. W. S. Steel.

Seychelles.
    Dr. I. W. B. Nye.

South Africa.
    Dr. J. W. C. Geyer.

Southern Rhodesia.
    Mr. J. Ford.

Tanganyika.
    Dr. A. C. Evans.

Trinidad.
    Mr. M. G. Emsley (Imperial College of Tropical Agriculture).
    Prof. T. W. Kirkpatrick (Imperial College of Tropical Agriculture).

Uganda.
    Mr. J. Bowden.
    Mr. J. M. B. Harley (East African Trypanosomiasis Research Organization).

United Kingdom.
    Mr. J. D. Bletchly.
    Mr. W. P. L. Cameron.
    Mr. R. Chamberlain.
    Mr. M. Crooke.
    Dr. D. W. Hall.
    Mr. G. V. B. Herford, C.B.E.
    Mr. W. E. H. Hodson.
    Mr. F. H. Jacob.
    Dr. D. S. MacLagan.
    Dr. K. Mellanby, C.B.E.
    Dr. I. Thomas.
    Prof. V. B. Wigglesworth, C.B.E., F.R.S.
    Mr. D. W. Williams.
    Mr. D. W. Wright.

In addition the following attended as observers:—

Australia.
Mr. T. Greaves.

South Africa.
Dr. D. P. Annecke.
Dr. L. L. J. Ossowski.

United Nations.
Mr. O. B. Lean (United Nations Food and Agriculture Organization).

Programme

The programme was as follows:—

Wednesday, 6th July

10.30 a.m. Opening Plenary Session of Delegates presided over by the Chairman of the Executive Council of the Commonwealth Agricultural Bureaux.
2.30 p.m. First meeting of Committee.

Thursday, 7th July

10 a.m. Open Meeting: " Recent developments in insecticides for crop protection."
Chairman: Dr. R. A. E. Galley.
Speaker: Dr. J. T. Martin.
11.30 a.m. Open Meeting: " Problems in the use of insecticides."
Chairman: Professor H. G. H. Kearns, O.B.E.
Speaker: Dr. A. B. Hadaway.
2.15 p.m. Open Meeting: " Hazards and precautions associated with the use of pesticides."
Chairman: Dr. I. Thomas.
Speakers: Dr. J. M. Barnes.
Dr. E. J. Miller.
4 p.m. Open Meeting: " Research on stored-products pests and their control."
Chairman: Mr. G. V. B. Herford, C.B.E.
Speakers: Dr. D. W. Hall.
Dr. J. A. Freeman, O.B.E.
Dr. E. A. Parkin and Mr. A. A. Green, M.B.E.

Friday, 8th July

10 a.m. Open Meeting: " Biological control of insects and weeds."
Chairman: Dr. W. Cottier.
Speaker: Mr. Frank Wilson.
11.30 a.m. Open Meeting: " Insect attack in relation to the physical characters and physiological state of the plant."
Chairman: Professor O. W. Richards, F.R.S.
Speakers: Dr. N. D. Holmes.
Mr. R. G. Fennah.
2.30 p.m. Second meeting of Committee.

Saturday, 9th July

Visit to Rothamsted Experimental Station, Harpenden.

Monday, 11th July

10 a.m. Open Meeting: " Recent investigations on timber-boring beetles."
Chairman: Dr. M. L. Roonwal.
Speakers: Mr. J. D. Bletchly.
Mr. Tecwyn Jones.

Monday, 11th July—*continued.*

11.30 a.m. Open Meeting: " Termite control in afforestation projects and constructional timbers."
Chairman: Mr. D. Rhind, O.B.E.
Speakers: Mr. W. V. Harris.
Mr. W. A. Sands.

2.30 p.m. Meeting of Sub-committee.

Tuesday, 12th July

10 a.m. Open Meeting: " The utilisation of pathogenic organisms in the control of insect pests."
Chairman: Professor G. C. Varley.
Speakers: Dr. K. M. Smith, C.B.E., F.R.S.
Dr. L. L. J. Ossowski.

11.30 a.m. Open Meeting: " Recent advances and current trends in the study and control of tsetse flies and trypanosomiasis."
Chairman: Dr. T. A. M. Nash, C.M.G.
Speakers: Mr. J. Ford.
Dr. K. S. Hocking.

2.15 p.m. Open Meeting: " Developments in the Study of the Dispersal of Insects."
Chairman: Dr. B. P. Uvarov, C.M.G., F.R.S.
Speakers: Miss Z. V. Waloff.
Dr. C. G. Johnson.

4 p.m. Open Meeting: " Recent research on locusts and their control."
Chairman: Dr. J. W. C. Geyer.
Speakers: Dr. P. T. Haskell.
Dr. R. C. Rainey.

Evening. Reception for the Delegates given by the President and Fellows of the Royal Entomological Society of London.

Wednesday, 13th July

Visit to the East Malling Research Station, East Malling, Kent.

Thursday, 14th July

10 a.m.* Open Meeting: " Developments in the study of plant viruses and their vectors, and their bearing on control measures."
Chairman: Mr. F. C. Bawden, F.R.S.
Speakers: Dr. M. A. Watson.
Dr. A. F. Posnette.
Dr. J. S. Kennedy.
Dr. L. Broadbent.

2.15 p.m.* Open Meeting: " The link between research work and its application in the field of plant protection."
Chairman: Professor V. B. Wigglesworth, C.B.E., F.R.S.
Speakers: Dr. A. P. Arnason.
Mr. F. H. Jacob.
Dr. G. Watts-Padwick.
Mr. A. R. Melville.
Mr. F. A. Squire.

Evening Official Reception for Delegates given by Her Majesty's Government at Lancaster House, St. James's, S.W.1.

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* Joint meetings with the Sixth Commonwealth Mycological Conference.

Friday, 15th July

9.30 a.m. Final meeting of Committee.
3 p.m. Closing Plenary Session of Delegates.
5.30 p.m. Informal Reception for Overseas Delegates given by the President and Council of the Institute of Biology.

Monday, 18th July

Visit to the Pest Infestation Laboratory, Slough.

Place of Meetings

The plenary sessions of the Conference were held in the Meeting Room of the Royal Entomological Society of London, at 41, Queen's Gate, London, S.W.7; and the committee meetings in the Council Chamber of the Society or the Board Room of the British Museum (Natural History), Cromwell Road, London, S.W.7. The open meetings of the Conference, the last two of which were held jointly with the Sixth Commonwealth Mycological Conference, took place in the Memorial Hall of the Royal Geographical Society, Kensington Gore, London, S.W.7.

These arrangements were made possible, respectively, by the courtesy of the President and Council of the Royal Entomological Society of London, the Director of the British Museum (Natural History) and the Director and Council of the Royal Geographical Society.

Opening of the Conference

The Conference assembled on the 6th July. The Chair was taken by Mr. A. Perera, Chairman of the Executive Council, Commonwealth Agricultural Bureaux, who welcomed the delegates in the following speech:—

Although not an entomologist myself, it gives me great pleasure to be associated with you at this Conference. There are fifty-six delegates and observers here, from twenty-one territories of the Commonwealth, and also a representative from the Republic of Ireland and one from the United Nations Food and Agricultural Organization. I extend a cordial welcome to each and all.

Several of you may have attended previous Conferences, but several, perhaps, have not done so. It may be helpful to give something of the background of these Conferences, of which the function has somewhat altered over the years. If, in doing so, I repeat what is already known to you, you must forgive me.

These Conferences, from their inception, have fulfilled a dual purpose. The first took place in 1920 and the remainder have followed at approximately five-year intervals. One purpose has been to provide an opportunity for economic entomologists from the various Commonwealth countries to meet together and discuss their scientific problems. The other has been to allow them, as technical representatives of the countries that jointly finance the Commonwealth Institute of Entomology and the Commonwealth Institute of Biological Control, to consider the work of the two Institutes, and to see how far their activities meet the needs of their countries, and to suggest any modifications that may seem desirable.

These Conferences are concerned with applied entomology and thus with pests of agriculture and associated problems of importance, such as insect-borne diseases. Although many of the Commonwealth countries have their own Universities and maintain their own research institutions which contribute to the advancement of fundamental knowledge as well as to the solution of local problems, the United Kingdom has played an important part in the development of economic entomology, both on account of the research carried out here and on account of the facilities it has offered for training those economic entomologists responsible for research work in the less developed territories. It is probable that such territories will for some time continue to need assistance from the more technically advanced countries of the Commonwealth.

The Conferences thus play an important part in bringing together research workers from this country and those working overseas. A varied programme of scientific discussions has been arranged for the open meetings at the present Conference, and should provide an opportunity for surveying recent advances in knowledge in different subjects and for an exchange of views between workers interested in different aspects of them. It is hoped that they will lead to further advances, both in understanding the problems and in applying the methods of solving them.

The second purpose of the Conferences is concerned, if only indirectly, with the finance and administration of the Institutes. This aspect is primarily the responsibility of the Executive Council of the Commonwealth Agricultural Bureaux. The Bureaux, which were created to serve the needs of each of the agricultural sciences along the lines pioneered, in respect of entomology, by the Imperial Bureau of Entomology, are based on a common plan, and in the Executive Council all representatives of contributing countries have an equal place, irrespective of the size of the contribution of their respective countries. It is one of the functions of the Executive Council to convene this Conference of Commonwealth entomologists, although the agreement to hold such a Conference is the responsibility of the Governments of the various Commonwealth territories, which likewise appoint their delegates. The organisation of the Conference is one of the duties that falls on the Commonwealth Institute of Entomology, and the Director, in consultation with the Director of the Commonwealth Institute of Biological Control, has made provision for considering the affairs of both Institutes.

Consideration of the work of the Institutes forms a part of the comprehensive review of the Commonwealth Agricultural Bureaux organisation undertaken by the Review Conference such as is due later this year. There the work of each Institute and Bureau is examined, proposals for making modifications or increasing staff are considered, and as a result recommendations are transmitted to the respective Governments indicating the needs of the organisation.

Although the task of determining the finances and reviewing the work of the two entomological Institutes is now undertaken by the Review Conference, it is of importance that the views of the present Conference, which comprises the entomologists who make use of the services of these Institutes, should be made known as regards technical matters affecting them. The recommendations of this Conference cannot fail to be of the greatest assistance to the delegates attending the forthcoming Review Conference.

The Conference will accordingly be asked to consider the memoranda on the work of the two Institutes, which have been prepared by the Directors and have been distributed to the delegates. It is suggested that after each Director has introduced the memorandum on the work of his Institute, delegates should raise such points as seem to them to require consideration, and that the Conference should then appoint a Committee to consider them in detail.

Before concluding, it is appropriate to refer to changes in the Directorships of the two Institutes that have occurred since the previous Conference. Dr. W. R. Thompson, who was in charge of the Institute of Entomology's Parasite Service from its inception, and subsequently of the Institute of Biological Control that succeeded it, retired from the Directorship in 1958, and has been succeeded by Dr. F. J. Simmonds. Dr. W. J. Hall retired from the Directorship of the Commonwealth Institute of Entomology in 1958, and I am glad to be able to say that he is still attached to the Institute. He has been succeeded by Mr. E. O. Pearson, who has had the task of organising this Conference, assisted by Mr. R. G. Fennah, who was appointed as Assistant Director in 1958. Most of us are aware how efficiently they have carried out their duties, and we are fortunate in having them as Directors, and hope that we shall have the benefit of their services for many years.

It is with much regret that I have to refer to the death, last year, of Sir Guy Marshall, who was Director of the Institute of Entomology from its foundation in 1913 until 1942, after which he was a part-time worker on the staff for a further seventeen years. Associated with him was Dr. Sheffield Neave, Assistant Director of the Institute from its foundation and subsequently Director from 1942 to 1946. Although Dr. Neave is no longer connected with the Institute you may wish to send him an appropriate message of greeting.

I hope that the meetings will be of the greatest benefit to all present, and now declare the Conference open.

Formation of Committees

After the Conference had been formally opened the Director of the Commonwealth Institute of Entomology discussed briefly the Memorandum (Appendix I) on the work of the Institute for the past six years. He was followed by the Director of the Commonwealth Institute of Biological Control, who dealt with a corresponding Memorandum on the work of that Institute (Appendix II). Both memoranda had previously been circulated to the delegates.

After brief discussion, the Conference proceeded to appoint a committee to consider the memoranda in detail. The committee was constituted as follows:—

Mr. G. V. B. Herford (Chairman)	United Kingdom.
Dr. A. P. Arnason	Canada.
Mr. G. K. A. Buahin	Ghana.
Dr. W. Cottier	New Zealand.
Mr. J. Ford	Southern Rhodesia.
Dr. R. A. E. Galley	Colonial Office.
Dr. J. W. C. Geyer	South Africa.
Prof. T. W. Kirkpatrick	Trinidad.
Mr. E. McMahon	Republic of Ireland.
Mr. R. A. Melville	Kenya.
Dr. M. L. Roonwal	India.
Mr. F. A. Squire	Nigeria.
Mr. F. Wilson	Australia.
Enche Ahmad Yunus	Federation of Malaya.

It was agreed that the Committee should form a Sub-Committee to consider the work of the Commonwealth Institute of Biological Control, and this was later constituted as follows:—

Mr. F. Wilson (Chairman)	Australia.
Dr. A. P. Arnason	Canada.
Dr. W. Cottier	New Zealand.
Dr. J. W. C. Geyer	South Africa.
Mr. F. H. Jacob	United Kingdom.
Prof. T. W. Kirkpatrick	Trinidad.
Mr. A. R. Melville	Kenya.
Mr. G. M. Roddan	Colonial Office
Dr. M. L. Roonwal	India.

Dr. D. P. Annecke and Dr. L. L. J. Ossowski, both from South Africa, were invited to attend the meeting of the Sub-Committee as observers.

Mr. E. O. Pearson, Mr. R. G. Fennah and Dr. F. J. Simmonds attended the Committee meetings, but not as members, and Mr. R. F. Avery and Capt. H. S. Bushell, both of the Commonwealth Institute of Entomology, were present at the first two meetings of the Committee, but likewise not as members.

An account of the discussions in committee is given in Appendix III. The Committee's recommendations were submitted at the final plenary session of the Conference and, after slight emendation, were adopted as resolutions of the Conference.

Papers and Discussions

The papers read at the open meetings of the Conference, together with a summary of the discussions that followed, are printed as Appendix IV of this report.

Official Reception

Her Majesty's Government in the United Kingdom entertained the delegates to the Commonwealth Entomological and Mycological Conferences at an official reception held at Lancaster House, St. James's, on the evening of the 14th July. The Minister of Science and Lord President of the Council, the Right Honourable Viscount Hailsham, Q.C., received the guests and gave a short address of welcome to the delegates. Mr. F. Wilson (Australia) replied on behalf of the delegates to the Conferences.

Visits

Visits were made to Rothamsted Experimental Station, East Malling Research Station, and, after the close of the Conference, to the Pest Infestation Laboratory, Slough.

Proceedings at the Final Meeting

At the final meeting the chair was again taken by Mr. A. Perera. The conference considered the report of the Committee, presented by Mr. G. V. B. Herford, and while doing so discussed suggestions regarding the time and place of the next Conference. The recommendations of the Committee were adopted as the resolutions given below. The Chairman in his closing speech thanked Mr. Herford for his services as chairman of the Committee, Mr. Pearson, Mr. Fennah and the staff of the Commonwealth Institute of Entomology for the efficient arrangements which had been made for the Conference, and Dr. Simmonds for his assistance. Dr. M. L. Roonwal then proposed a vote of thanks to Mr. Perera for his kindness in presiding at the Plenary Sessions, and this was carried with acclamation.

Conclusions and Resolutions

1. The Conference desires to record its appreciation of the services rendered to scientific workers in the Commonwealth by the Commonwealth Institute of Entomology and the Commonwealth Institute of Biological Control, and to express the hope that at the Commonwealth Agricultural Bureaux Review Conference to be held in August–September 1960, satisfactory financial arrangements, including adequate provision for contingencies, will be made to enable the services of these Institutes to be maintained and, where necessary, extended.

2. The Conference notes with appreciation the careful consideration given by the General Committee and its Sub-Committee to the matters brought before them and makes the following resolutions (3–26) based on the recommendations put forward by the Committee.

Work of the Commonwealth Institute of Entomology

3. The Conference desires to record its appreciation of the valuable services rendered by Dr. W. J. Hall, the former Director of the Institute.

4. The adequacy of the coverage of the literature in economic entomology provided by the *Review of Applied Entomology* is proving increasingly difficult to maintain and must inevitably be reduced with each increase in the volume of the literature unless steps are taken to remedy the situation. In view of the importance that entomologists throughout the Commonwealth attach to the abstracts in the factual form provided by the *Review*, it is accordingly recommended that provision should be made for three additional members of the editorial and abstracting staff in the quinquennium 1962–67. Furthermore, it is urged that every possible step should be taken to ensure that salaries are adequate to attract and retain abstracting staff.

5. The Conference commends the efforts being made to reduce the arrears of indexing of the *Review of Applied Entomology* and notes with satisfaction the progress made towards the pre-war position in which the index to Series A appeared eight months, and that of Series B five months, after the issue of the December part of the relevant volume. In view of the value of the indexes in their present form, and of their influence on the use of the *Review* as a permanent work of reference, and consequently on the sale of back numbers, their standard should not be reduced in order to accelerate their production.

6. The systematic part of the *Insecta* section of the *Zoological Record* is essential to the work of insect taxonomists throughout the world, while its other two parts provide a bibliography of publications on entomology not covered by the *Review of Applied Entomology* and an index to the subjects with which these deal. The Conference regards its production as an important feature in the services rendered by the Institute and recommends that steps be taken to ensure its continued coverage of the growing volume of entomological literature.

7. The Conference notes that the present authorised establishment of the Identification Service of the Institute, together with the assistance it receives from workers in the British Museum (Natural History) and others, enables it to deal expeditiously with material of economic significance currently received for naming, within the limitations of existing taxonomic knowledge. The unsatisfactory position that exists in certain groups, notably the parasitic Hymenoptera, as regards the proportions that can be named to species can only be remedied by more taxonomic research in these groups. It would adversely affect the work of Commonwealth entomologists if the time spent on routine identifications were to be reduced and it is accordingly recommended that provision be made in the next quinquennium for two additional specialists, of whom one should work on the parasitic Hymenoptera and the other mainly on the Diptera.

Reviews of Work

8. There is a general consensus of opinion that a useful purpose is served by the Reviews of Work in Economic Entomology in the Commonwealth prepared in connection with the Conference and published as a part of its Report, and that similar reviews, which should be shorter and more uniform in presentation, should be prepared in the future.

List of Current Research Projects

9. The compilation of a list of current research projects in economic entomology that was undertaken by the Commonwealth Institute of Entomology as a result of a resolution of the Sixth Commonwealth Entomological Conference was followed by very few requests for the information that it was designed to supply and it is recommended that this compilation should not be repeated.

Directory of Institutions Engaged in Research in Economic Entomology

10. The Conference is of the opinion that the information that would be furnished by a directory of institutions where work is being done in economic entomology is available, as regards the Commonwealth, in the *List of Research Workers in Agriculture, Animal Health and Forestry* published at intervals by the Commonwealth Agricultural Bureaux organisation, and that to divert the resources of the Commonwealth Institute of Entomology to the preparation and maintenance of such a directory on a world basis would not be justified.

Taxonomic Research

11. The Conference reaffirms the views expressed by the Sixth Commonwealth Entomological Conference regarding the importance of expanding research in insect taxonomy and the key position occupied by the British Museum (Natural History) in relation to this. It records its appreciation of the facilities afforded by the Museum to the specialist staff serving with or attached to the Commonwealth Institute of Entomology, but is concerned lest the desirable expansion of taxonomic research by the staffs of the Museum and the Institute, by visiting taxonomists and by students should be limited by inadequacy of the space available to the Department of Entomology.

Phyto-Sanitary Co-operation in Africa

12. The Conference notes with great satisfaction that the Inter-African Phyto-Sanitary Commission has now been established, thus implementing the suggestions put forward by the Fifth Commonwealth Entomological Conference in 1948.

Work of the Commonwealth Institute of Biological Control

13. The Conference desires to record its appreciation of the valuable services rendered by Dr. W. R. Thompson, the former Director of the Institute.

14. The recommendation of the 1954 Conference to establish an East African Station is endorsed, subject to a sufficient demand for projects in the area. The establishment of such a station would involve the appointment of the two additional entomologists recommended by the previous Conference, and no capital expenditure on buildings would be proposed until the Station had proved its long-term value.

15. It is considered that the work of the Indian and Pakistan Stations has developed very satisfactorily, and has fully justified the approval given to their establishment by the last Conference.

16. The present system of renting laboratory accommodation at the European and West Indian Stations is unsatisfactory, and in view of the proven long-term value of these Stations it is recommended that permanent laboratory buildings be provided.

17. The nature of the work undertaken by the Institute makes it very desirable that the Director should spend much time at its Stations, and should visit Commonwealth and other countries from time to time in order to further the work of the Institute.

18. Provided that Resolution 17 is accepted, it is considered that from an entomological point of view the location of the headquarters of the Institute is of no great consequence.

19. Certain pests are of importance to a number of Commonwealth countries. It would be more efficient and economical if biological-control investigations relating to such species were undertaken on a co-operative basis. The Institute should foster development along these lines.

20. The Institute is at present collaborating with entomological organisations outside the Commonwealth to the advantage of all countries concerned. Such collaboration is highly desirable and should be extended as circumstances permit.

21. The work of the Institute inevitably entails research on the problems which it is requested to investigate. It is desirable, within limits to be determined for each individual project, that this research aspect should not be minimized.

22. Applied insect pathology comes within the scope of the Institute. It is recognized that the Institute has had great difficulty in finding suitable staff to develop this aspect of its activities. The Director should report on progress in this matter to the next Conference.

23. The Parasite Catalogue should be completed and brought up to date in its present form as speedily as possible. Subsequently the Institute should produce a critical Parasite Catalogue, the form of which should be determined by the Director in consultation with the entomological organisations of the Commonwealth.

24. The progress made in the preparation of reviews of biological control work in the different areas of the Commonwealth is noted. It is important that these reviews should be completed as soon as possible.

25. The scientific staff of the Institute should be increased above its present authorised establishment by three entomologists. This, with appointments to the three existing vacancies, would allow for two entomologists at the proposed East African Station, one insect pathologist, and staff for additional work at present Stations.

Future Commonwealth Entomological Conferences

26. The Conference reaffirms the value of meetings at approximately five-year intervals of entomologists drawn from as many Commonwealth countries as possible. It recommends that the Eighth Commonwealth Entomological Conference should be held in advance of the Commonwealth Agricultural Bureaux Review Conference following that of 1960, at a date to be recommended to Governments as far in advance as possible by the Executive Council of the Commonwealth Agricultural Bureaux.

Acknowledgements

27. The Conference wishes to tender its grateful thanks to Her Majesty's Government in the United Kingdom and to the Royal Entomological Society of London for the hospitality extended to it, and to the last named also for the privilege of using its Council and Meeting Rooms. It also wishes to thank the Council of the Royal Geographical Society for the use of their Memorial Hall for the Open Meetings of the Conference, and the Trustees of the Natural History Museum for the use of their Board Room for one of the meetings of the Committee of the Conference.

28. The Conference wishes that its grateful thanks be conveyed to Mr. F. C. Bawden, Dr. F. R. Tubbs, and Mr. G. V. B. Herford, and their staffs, for the welcome accorded to the delegates on the occasions of their visits to Rothamsted Experimental Station, the East Malling Research Station, and the Pest Infestation Laboratory, and for the admirable arrangements for the display and explanation of the work in progress at these centres.

APPENDIX I

MEMORANDUM ON THE WORK OF THE COMMONWEALTH INSTITUTE OF ENTOMOLOGY FROM 1ST APRIL, 1954 TO 31ST MARCH, 1960

During the six years that have elapsed since the Sixth Commonwealth Entomological Conference, the Institute has maintained and in general improved its services to the Commonwealth. The period has been, in some respects, a difficult one. The Agricultural Bureaux Review Conference which met in 1955 gave support to those recommendations of the previous year's entomological Conference that had a bearing on the staffing and finances of the Institute, but salary revisions have resulted in increases of the order of thirty-six per cent. over the salary rates current in 1955, upon which the Institute's finances for the quinquennium 1957–1962 were based. These have been, to some extent, offset by the increase in the Institute's total receipts from publications, which reached, in 1956–57, a record figure of £15,581. Nevertheless, in implementing recommended increases in staff, it has been necessary to bear in mind the overall financial position, and exercise prudence. There has been difficulty, in any case, in recruiting and retaining certain vital grades of staff, and in recent years the Institute has lost the services of some of its most experienced workers. The emphasis has thus had to be placed on the Institute's existing, major activities rather than on expanding into new fields.

2. In December 1954, negotiations were completed for the lease of No. 56 Queen's Gate, and the removal of the Publications Office and Library to the new premises was accomplished in seven days in May 1955. The extra space so acquired was greatly needed and has enabled the Institute's entire stock of publications, and library, to be brought together once more under one roof (Resolution 26).* In 1958 the opportunity arose and was taken of buying the freehold of the premises, which are conveniently adjacent to the Natural History Museum and also to the Royal Entomological Society of London, from whom our former premises were leased and with whom our association has been so long and happy.

Identification of Insects

3. At the Sixth Commonwealth Entomological Conference it was recommended (Resolution 7) that the identification service of the Institute required strengthening by the appointment of three further specialists, one of whom should work on the Acarina, and this recommendation was accepted by the Commonwealth Agricultural Bureaux Review Conference, 1955. Two of these posts have since been filled, and the third will be if it is warranted by the financial position nearer the end of the present quinquennium (1957–62).

4. The number of identifications sent out by the Institute in the past six years is given in the following Table.

Year	Africa	America	Asia	Australasia, New Zealand & Pacific Is.	Europe	Total
1954–55	2,956	375	1,390	751	711	6,183
1955–56	3,568	333	1,802	848	653	7,204
1956–57	3,931	248	1,681	1,602	529	7,991
1957–58	2,680	280	2,210	1,338	581	7,089
1958–59	3,889	119	1,322	1,040	578	6,948
1959–60	3,732	235	2,098	1,193	293	7,551

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* In this Memorandum, references to numbered resolutions are to those given on pp. 10–13 of the *Report of the Sixth Commonwealth Entomological Conference*, 1954.

5. The identification work is carried out by a staff of ten full-time specialists and four who work on a part-time basis. The Institute has lost the services of three of its most experienced specialists. Dr. F. I. van Emden, who was an authority not only on the Diptera, but also on the larvae of the Coleoptera, died in August, 1958, and Sir Guy Marshall, whose knowledge of the Curculionidae was unrivalled, in April, 1959. Mr. N. C. E. Miller retired in August, 1958, after ten years' service as specialist in Hemiptera.

6. In 1955, Mr. D. MacFarlane took up appointment as specialist in Acarina, and in July, 1959, Mr. R. W. Crosskey and Dr. M. S. K. Ghauri, as specialists in Diptera and Hemiptera, respectively; in October 1959, Dr. B. J. Selman was appointed to work on the Chrysomeloid Coleoptera. There was a delay of nearly a year in filling the vacancies in the Diptera and Hemiptera, during which both groups were handled by Mr. R. G. Fennah, whose first year as Assistant Director was thus occupied, to a considerable extent, with routine naming. Through his efforts, no serious interruption of our identification services took place. Invaluable help is given by Mr. G. E. Bryant, Mr. R. J. Collins, Dr. Dirsh and Dr. W. J. Hall, working part-time as specialists in Coleoptera, Lepidoptera, Orthoptera and Hemiptera, respectively. Mr. W. V. Harris, Officer-in-Charge of the Colonial Termite Research Unit, which is attached to the Institute, determines termite material submitted for identification.

7. Mr. E. A. J. Duffy spent three months in Ghana and Nigeria in 1955 and a similar period in Trinidad and British Guiana in 1957, collecting material for his series of monographs of the immature stages of timber beetles; the expenses of these visits were met by the Governments concerned, assisted, in the case of the second, by the Colonial Development and Welfare funds and the Percy Sladen Trust.

8. Two members of the Colonial Pool of Entomologists, Mr. E. S. Brown and Dr. I. W. B. Nye, while in the United Kingdom between assignments abroad, have carried out taxonomic studies arising from the projects on which they had been engaged.

9. Members of the curatorial staff of the British Museum (Natural History), as in former years, have kindly undertaken identifications of insects in certain groups, and the Institute has also been able to avail itself of the assistance of other specialists working in the United Kingdom, the Commonwealth and elsewhere. The help of all has been much appreciated and is gratefully acknowledged. It is with much regret that we have to record the loss of three of these helpers, Dr. H. F. Barnes, Mr. C. L. Collenette and Dr. Karl Jordan, who for many years dealt with the identification of gall-midges, Lymantriidae and Anthribidae, respectively.

10. Between 1954 and 1960, 54,669 specimens have been presented to the British Museum (Natural History) and these have included the types of 678 new species and specimens of a further 1,490 species not previously represented in the Museum collections.

11. The Institute is today able to give better service, as regards naming insects, than at any former time: all arrears have been overtaken (including, notably, those in the Acarina) and collections are being dealt with expeditiously.

12. The degree of precision with which identifications can be made depends, of course, upon the state of taxonomic knowledge in the group concerned and the extent to which this is reflected in the indexing and arrangement of the working collections of the Museum. There is still an urgent need for an intensification of taxonomic research. Recommendations were made at the Sixth Commonwealth Entomological Conference regarding the supply and training of taxonomists, and these were duly transmitted to the organisations referred to by the Conference (Resolutions 18–20). The Institute has attempted, within the limit of its terms of reference, to help in implementing these recommendations, but the overall picture in insect taxonomy cannot be said to have changed greatly.

Publications

Review of Applied Entomology

13. The production of this monthly publication, now in its 48th volume, continues to be one of the Institute's most important activities. Neither the flow of literature requiring abstracting, nor its complexity, show any signs of diminishing, and it has been necessary to continue the policy, approved by the 1948 and 1954 Conferences, of selection of material

for abstracting. Grave difficulties have been experienced in recruiting and retaining abstractors with linguistic qualifications: since the 1954 Conference, nine abstractors have left and eight have been recruited, leaving us, on balance, with one less on our strength. Apart from the restriction which this shortage of abstractors places on the coverage of the literature (particularly foreign literature), the time that has to be spent on training new recruits seriously interferes with normal editorial duties and has contributed to the delay in the production of indexes.

14. The number of subscribers to Series " A " and Series " B " and the total cash receipts from sales of the *Review* over the past six years, with corresponding figures for 1953 for comparison, are shown in the Table below.

Vol.	Year	No. of subscribers " A "	No. of subscribers " B "	Total cash receipts (£)*
41	1953	1,232	1,025	5,197
42	1954	1,300	1,085	5,387
43	1955	1,349	1,083	5,290
44	1956	1,381	1,108	7,592
45	1957	1,391	1,073	6,603
46	1958	1,331	1,039	7,053
47	1959	1,361	1,036	7,039

15. The number of subscribers, which showed a steep rise in the post-war years, reached a maximum in 1957. The slight fall that occurred the following year was due mainly to subscribers reducing to one series only when formerly they had taken both, and probably reflected a reaction to the substantial increase (fifty per cent.) in the subscription rate that had to be made in 1957 to offset rising costs, the price of Series A being raised to £3 (from £2) and of Series B to 30s. (from 20s.).

16. The demand for back numbers of the *Review*, including complete sets, continues to be high, and receipts from this source have averaged some £1,500 per annum. To continue to be able to meet this demand, certain volumes of which supplies were running low have been reprinted by the xerographic process.

17. A defect from which the *Review* has suffered for some years past has been the delay in the issue of indexes. At the beginning of 1959 it became possible to put into effect special arrangements to overcome these arrears, and in the past eighteen months five indexes have been issued (those to Vols. 44, 45 and 46 of Series " A " and to Vols. 45 and 46 of Series " B ") and it is hoped to be up to date by the end of this year.

18. A new edition of *Serial Publications Examined* was issued to all recipients of the *Review* in April, 1960.

19. Production of the *Review* was maintained uninterrupted by the prolonged printing dispute of 1959; two successive issues (June and July 1959) were prepared by a combination of varityping and xerographic reproduction, and in format, type face and general appearance were close replicas of the normal issue. The exercise, though costly, afforded useful experience of a possible alternative to normal methods.

Bulletin of Entomological Research

20. This quarterly journal reached its jubilee in 1959 and is now in the 51st year of its publication. It continues to serve, particularly, as an important medium for the publication of the results of research done in the developing territories of the Commonwealth. The increase in size initiated in 1950 has been maintained; the aim is about 800 pages (exclusive of index), but this has occasionally been exceeded so as to accommodate particularly lengthy but important papers. Figures for the size of volumes, number of subscribers, and total cash receipts (including those from sales of reprints and back numbers) during the past six years are given below. The rise in the numbers of subscribers received a check following the substantial price increase (to £5, from £3) that became necessary in 1957.

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* For the financial year ended 31st March of the next volume year.

Vol.	Year	Pages (exclusive of index)	Plates	Articles	Subscribers	Total cash receipts £*
44	1953	810	16	58	848	3,903
45	1954	801	44	59	871	3,991
46	1955	923	24	61	892	4,778
47	1956	822	16	56	942	6,700
48	1957	866	15	65	966	5,887
49	1958	802	29	63	940	5,401
50	1959	824	19	58	945	6,049

Zoological Record, part Insecta

21. The *Insecta* section, which is much the largest section of the *Zoological Record*, continues to be prepared by the Institute and provides, in its systematic section, an essential service for insect taxonomists throughout the world, as well as, by its subject index, a guide to the research in " pure " entomology, as distinct from the work noticed in the *Review of Applied Entomology*. Some data for the *Insecta* are appended; the most recent volume (Vol. 95) is the largest ever to be prepared.

Vol.	Literature of	Issued	No. of pages	No. of papers recorded	Sales to 31st December 1959†
90	1953	1955	534	4,024	457
91	1954	1956	546	4,060	431
92	1955	1957	536	4,005	502
93	1956	1958	536	3,444	461
94	1957	1959	576	3,877	394
95	1958	1960	650	4,521	–

22. The difficulties of maintaining an adequate recording staff have been similar to those met in the case of abstracting staff for the *Review*; since 1954, three trained recorders have left, and the greatest credit reflects on the two present recorders, Miss L. Krass, who joined the staff in February 1956 and took charge of the *Insecta* four months later, and Miss J. E. Deam, who joined in 1957.

23. The Zoological Society of London defrays the cost of printing the *Insecta*, and makes an annual contribution towards the cost of its preparation; this sum was increased to £400 (from £175) in 1956 and, from the beginning of 1960, to £500. In addition, the Institute receives three-fifths of the proceeds of all sales of the *Insecta*; in 1959 this proportion amounted to £741.

Distribution Maps of Pests

24. The issue of these maps has been continued at the rate of twelve per annum. Their preparation is very time-consuming, particularly where the authenticity of any of the records is in question, and the number of subscribers remains small (264 in 1953; 336 in 1959), but it has been decided to increase the number issued to eighteen per annum in 1961.

Occasional Publications

25. Four works, each of considerable size, have been published during the period under review:

A Critical Review of the World Literature on the Lepidopterous Stalk Borers of Tropical Graminaceous Crops, by W. F. Jepson (127 pp.), in September 1954.

Report of the Sixth Commonwealth Entomological Conference, July 1954 (344 pp.), in December 1954.

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* For the financial year ended 31st March of the next volume year.

† These do not include copies of the *Insecta* section included in complete issues of the *Zoological Record* sold by the Zoological Society.

A Critical Review of the Techniques for Testing Insecticides, by J. R. Busvine (208 pp.), in December 1957.

The Insect Pests of Cotton in Tropical Africa, by E. O. Pearson, assisted by R. C. Maxwell Darling (355 pp.), in November 1958.

26. During the past six years (1954–55 to 1959–60, inclusive), 171 technical publications, totalling over 4,300 pages, have been published by members of the staff in scientific journals or as monographs. Most of this work represented taxonomic revisions associated with descriptions of new material, and some of the shorter papers were written expressly to furnish names for new species which had been recognised as of economic status. Of the larger taxonomic works completed, one, a monograph on the immature stages of African timber beetles, and another, on the Southern African species of the Melolonthid genus *Schizonycha*, have been published, and three others, dealing respectively with the immature stages of Neotropical timber beetles, with a group of African Tachinid flies, and with certain families of the Muscidae of India, have been in press for some time. Three items written for entomologists not specialising in taxonomy include two contributions to the " Handbooks of the British Insects " series, which provide a useful introduction to a study of the groups concerned, and a comprehensive treatise on the pests of a single crop in a single continent, in this case, of the cotton crop in Africa. Major projects still under way but approaching completion include a revision of the genus *Apanteles*, and of the Pseudococcidae of Africa.

The Library

27. During the past six years, the average annual growth of the library has been 204 (238) bound volumes, 1,447 (1,239) pamphlets and parts of 686 (626) periodical publications, the figures in brackets being the annual average for the previous six years. Works issued on loan averaged 1,602 (1,633) annually. The library was in daily use by the staff and by visitors from various parts of the world.

28. The library now contains 14,479 bound volumes and 48,804 pamphlets. The author catalogue of monographs and separates is up-to-date and the entomological contents of 70·2 per cent. of the volumes of periodicals in the library have been catalogued. The sheaf catalogue of serial and official publications and the subject index to monographs are both up to date.

29. The whole of the library stock is now housed at 56, Queen's Gate, the removal from the previous building being accomplished in one week in May 1955. The library was completely closed to borrowers for only two weeks, although certain sections were inaccessible at times after that while sorting and rearranging were carried out. The volumes removed to Horsham for storage were returned in January 1956. More accommodation can now be provided for visitors who need to work in the library for either long or short periods.

30. In August 1954, the library's Russian holdings were finally incorporated into the Russian Union Catalogue at the National Central Library and notification slips are dispatched upon receipt of individual Russian books to keep that catalogue up to date. During the year 1958–59, the list of the library's holdings was revised for the new edition of the *World List of Scientific Periodicals* and for the *British Union Catalogue of Current Periodicals*. *Serial Publications Examined*, issued in connection with the production of the *Review of Applied Entomology*, was completely revised early in 1960, so that it now records all serial publications received in the Institute's library and regularly scanned in the preparation of the *Review of Applied Entomology*; it does not include the other publications scanned in the preparation of the *Zoological Record*, part *Insecta* that are available in other libraries.

31. There has been a fairly steady demand for microfilms or photocopies of articles or extracts for entomologists overseas, a yearly average of sixty-three such extracts being provided over the past six years, mainly for workers in the Commonwealth.

32. Surplus publications have again been distributed to the Bureaux and to libraries in the Commonwealth and elsewhere, either direct or through the British National Book Centre. In return, the library has received publications donated or sent in exchange by institutions and individuals.

General Information

33. A steady inflow of enquiries from correspondents on specific problems has been maintained during the six-year period under review. As ever, their total range of subject-matter was wide, but most required data about particular insects, or bibliographical references to papers relevant to investigations in progress, while some called for verification of names in faunal lists. One such was the recently published *Agricultural Insects of East Africa*, which involved checking the names of between 3,000 and 4,000 species.

34. In addition to such enquiries from outside, others repeatedly arise within the Institute, mainly in the course of abstracting, and their answers, which not infrequently involve time-absorbing investigation, appear inconspicuously in the names of organisms and, to an increasing extent, of chemicals that appear in the Institute's publications.

The Pool of Entomologists

35. Mr. E. S. Brown was posted to the British Solomon Islands Protectorate from April 1954 to May 1957 to study the problem of immature nutfall of coconuts caused by *Amblypelta*. On returning, he spent some seven months at the Institute, preparing a series of papers on the results of his work, which were published in the *Bulletin of Entomological Research*. He was then seconded to the Foreign Office for three years, from December 1957, for work under the Economic Aid Agreement of the Central Treaty Organisation on the soun pest, *Eurygaster integriceps*. In May 1955, Mr. C. R. Wallace, having completed his reports on *Solubea poecila*, a pest of rice in British Guiana, and *Steirastoma breve*, affecting cocoa in Grenada, was assigned to the Gambia for approximately eighteen months to study the pre-harvest pests of the groundnut crop. On his return, he spent a short period at the Institute in 1957, and then undertook a two-year survey of the insect pests of the island of St. Helena, on which a comprehensive report has now been completed. Dr. I. W. B. Nye was appointed as the third member of the Pool in July 1955 and, after a preliminary period of study of material at the Institute, left for East Africa in February 1956 to carry out a two-and-a-half year survey of the pests of tropical cereal crops in that region (Resolution 23). After several months spent at the Institute on his return in further study of the material collected and in writing his report, shortly to be published as one of the series of Colonial Research Studies, Dr. Nye left in March 1959 for a short assignment to the Seychelles to assess the results of control measures taken against *Melittomma insulare* on the basis of Mr. E. S. Brown's earlier work on this pest of coconut palms. A modified form of treatment was devised and after being successfully applied in the island originally treated had been extended, by the time of Dr. Nye's departure in April 1960, to the main island.

Other Activities

36. Brief reference must be made to various other activities with which the Institute is associated or which were the subjects of resolutions at the Sixth Commonwealth Entomological Conference.

37. *Research on termites* (Resolution 21). The Colonial Termite Research Unit is attached to and administered through the Institute although it is financed from Colonial Development and Welfare funds and not by the Commonwealth Agricultural Bureaux organisation. The Officer-in-Charge, Mr. W. V. Harris, and other members of the Unit when they are in this country are accommodated at the British Museum (Natural History) and material acquired by the Unit is incorporated in the Museum collections. In the past six years, Mr. Harris has visited Australia, Malaya, Sarawak, North Borneo, East and West Africa, Nyasaland, the West Indies and British Honduras, and other members of the Unit have made termite-fauna surveys in Uganda (Mr. R. M. C. Williams) and in Nyasaland and Nigeria (Mr. W. A. Sands and Mr. W. Wilkinson). Investigations of measures for controlling termites in relation to forestry have recently been completed in Northern Nigeria (Mr. Sands) and initiated in British Honduras (Mr. Williams).

38. *List of Current Research Projects in Economic Entomology* (Resolution 8). This resolution proposed that the Institute should, at yearly intervals, ask each Commonwealth country for a list of current research projects in economic entomology, with their location

and the names of those in charge, so that this information could be provided by the Institute on request. A circular enquiry issued in January 1956 to all Commonwealth territories elicited, on the whole, a good response, information being received within the next nine months from about twenty-eight Colonies and three self-governing Territories, apart from Canada, which already publishes an annual list of current research projects. The Institute was thus in a fairly good position to answer requests for information on current research in economic entomology but, in the event, virtually no such requests have been received. It is apparent that the time spent by those in the Commonwealth territories collecting and transmitting the information, and by the Institute in collating it, would not be justified unless the information were actually to be published, and such publications revised and re-issued at regular and frequent intervals. This would be a quite substantial undertaking, outside the original terms of reference.

39. More recently, it has been suggested that Institutes and Bureaux should compile and publish Directories or Gazetteers of Institutions doing research in their respective fields. This would appear to be indistinguishable from the *Gazetteer of Agriculture and Forestry Research Stations in the British Commonwealth* formerly issued by the Commonwealth Agricultural Bureaux, which the 1955 Review Conference recommended should be discontinued.

40. There appears to be some conflict of opinion as to the precise nature and desirability of what is needed, and a clearer lead is sought, as regards economic entomology, from the Conference.

41. *Reviews of Work* (Resolution 24). The reviews of work in economic entomology in the various Commonwealth countries submitted for the Sixth Commonwealth Entomological Conference were duly published in the Conference Report, and a memorandum conveying the Conference recommendation that similar reports should be prepared for the present Conference, and setting out suggestions for their improvement, was circulated to all Commonwealth territories by the Institute in December 1959.

42. *Services of the Commonwealth Institute of Biological Control* (Resolutions 9–13). These are dealt with in memoranda prepared by the Director of that Institute and circulated to delegates at the present Conference.

43. *Inter-African Phyto-Sanitary Commission.* The Commission was set up, under the Phyto-Sanitary Convention for Africa South of the Sahara, in 1956 and Dr. J. Risbec was appointed as Scientific Secretary and accommodated in the Institute's premises at 56 Queen's Gate in October 1956. Under the terms of the Convention, the Directors of the Commonwealth Institute of Entomology and of the Commonwealth Mycological Institute constitute, with the Scientific Secretary, a Committee of Information, and make available to the Commission such information on matters concerning entomology (or plant pathology, as the case may be) as the Commission may require. A contribution to the finances of the Institutes is made by the Commission in respect of these services, and in each an officer has been specially appointed to deal with Commission matters. Three meetings of the Commission, each lasting several days, have been held in London, in 1957, 1958 and 1959 and each has been attended by the Director.

44. *Miscellaneous.* The services of the Director have continued to be required on a number of committees dealing with entomological research work overseas, including the Committee for Colonial Agricultural, Animal Health and Forestry Research, the Colonial Pesticides Research Committee, the Anti-Locust Research Committee, the Scientific Advisory Committee of the Empire Cotton Growing Corporation, the Advisory Committee on Agricultural Research in the Sudan, and a number of others.

Staff Changes

45. There have been a number of changes in the senior staff of the Institute, other than those mentioned elsewhere in this memorandum, during the six years that have elapsed since the Sixth Commonwealth Entomological Conference in 1954. Dr. W. J. Hall, C.M.G., M.C., who joined the staff in 1943 and succeeded Dr. S. A. Neave as Director in 1946, retired from that office in June 1958. He was a source of great strength to the Institute throughout the difficult post-war years, which were marked by the very rapid growth of

economic entomology throughout the Commonwealth and in which the Institute undertook or became associated with a number of new activities. He was succeeded by Mr. E. O. Pearson, and the post of Assistant Director thus left vacant was filled in October 1958 by Mr. R. G. Fennah, formerly of the Regional Research Centre in the West Indies, who has extensive experience of the entomological problems of that region and is an authority on the Fulgoroid Homoptera. Sir Guy Marshall, Director of the Institute from its foundation, in 1913, until 1942, and thereafter a part-time member of the staff, died in April 1959, at the age of eighty-seven. Sir Guy was appointed in 1909 as Scientific Secretary of the Colonial Office's Entomological Research Committee, from which the Institute stemmed, and he thus began an association that was to last for half a century. He remained actively at work, continuing to deal with all the Curculionidae received by the Institute for identification, until only a few weeks before his death. Capt. H. S. Bushell retired in January 1959, after thirty-nine years' service, for the greater part of which he was in charge of the *Review of Applied Entomology*, and it is difficult to exaggerate the importance of the part he has played in its development. He was succeeded as Assistant Editor of the *Review* by Mr. R. F. Avery, who joined the staff in 1936.

46. The Institute has been fortunate in obtaining the part-time services of both Dr. Hall and Capt. Bushell, and also those of Mr. W. H. Potts, formerly Chief Entomologist of the East African Tsetse and Trypanosomiasis Research Organization, who is assisting in the editing of the *Review*. Mr. G. S. Cotterell, who has had long entomological experience in West Africa, joined the staff in 1957 for special duties in connection with the Inter-African Phyto-Sanitary Commission.

47. In conclusion, I wish to record my deep appreciation of the unfailing support given by all members of the Staff of the Institute, and of the high sense of responsibility that has characterised their work.

E. O. Pearson, *Director*

APPENDIX II

MEMORANDUM ON THE ORGANISATION AND WORK OF THE COMMONWEALTH INSTITUTE OF BIOLOGICAL CONTROL

A report on the work of the Commonwealth Institute of Biological Control since the last Commonwealth Agricultural Bureaux Review Conference in 1955 may be divided roughly into three sections:—(1) developments in the general field of biological control, (2) the entomological work of the Commonwealth Institute of Biological Control in particular, (3) administrative matters affecting our Institute. These I will deal with as far as possible separately, although there is obviously no clear-cut line between them. The first two may be of more interest to the Commonwealth Entomological Conference, the last to the Commonwealth Agricultural Bureaux Review Conference. However, since they all affect our Institute it seems best to present them as a whole.

There have in the past few years been a number of important developments in the field of biological control of very definite interest to our Institute, and hence to these Conferences. As with other scientific advances, trends of thought usually develop from small beginnings over a long period, but there comes a stage when they crystallise into something more definite. I think that this has occurred comparatively recently in the field of biological control in relation to a number of different aspects of the work: (1) the development of insect resistance to chemical insecticides, (2) a deepening concern over the broader and long-term effects of continued utilisation of powerful modern insecticides, (3) increased attention to the possibilities of the use of insect pathogens, (4) the importance of studying not only a simple host/parasite or host/predator relationship, but the general ecology or biocoenotics of a number of hosts and their natural enemies, (5) further attention to the problems of determining the effects of various factors, including natural enemies, controlling field populations of insects, (6) a further development, which is perhaps only in its initial stages—the possibility of the use of genetic principles in obtaining better results in biological control.

These may be considered in somewhat greater detail.

The development of resistance by many species of insects to modern insecticides has been known for a long time, and more and more definite examples are being discovered. This has now become something rather to be expected following continued applications of insecticides. Naturally the reaction of different insect species is by no means uniform in development of resistance, and there are groups of insecticides having quite different effects in this regard. Also the chemists are obviously well aware of the importance of this, and are developing new compounds to counteract it. Nevertheless this problem of resistance has developed to a stage where entomologists and agriculturalists alike are becoming more and more concerned. Furthermore, it is becoming realised increasingly that the utilisation of powerful modern insecticides against a pest may entail important side effects in connection with the natural enemies of the pest in question, or affect adversely control of other insects living in the same environment. Work on mites in orchards, codling moth in apples, and scale insects on citrus, provide good examples of this. In addition there is the general problem of toxicity and the build up of toxins in the soil, etc.

As a result of this there has occurred a somewhat radical change of thought with regard to entomological problems in general, and this change was very apparent at the 1958 meeting of the Entomological Society of America—a meeting, I may add, well attended by entomologists interested primarily in chemical methods of control—and was further illustrated in the recent 1959 joint meetings of the Entomological Society of America and Entomological Society of Canada where the main general theme of the programme was that of alternatives to chemical control of insects.

Whilst this development is not specifically towards biological control, the limitations of which must, of course, be realised, there is a tendency now to consider more closely what the possibilities in this particular field are, even in connection with those problems where past work has not proven promising. As examples of this I would cite the codling moth in temperate areas, and the froghoppers, *Aeneolamia* spp., in the New World tropics. In the former resistance to chemical treatment has developed really alarmingly in many areas—notably the U.S.A., Canada, New Zealand and South Africa—and there is an increasing tendency to look again towards biological control as a help in this problem. It seems to me obvious that with modern standards of perfection demanded for marketable fruit biological control in cases such as this cannot provide the complete solution to the problem, but it does seem that it could be of very definite value.

The froghoppers, *Aeneolamia* spp., have long been recognised as serious pests of sugar cane in Trinidad and British Guiana, and in the past much work on the possibilities of biological control was carried out—without success. It was only with the development of the chlorinated hydrocarbon insecticides that efficient and effective control of those pests was obtained. However, again, resistance has developed, and whilst control by chemical means can still be obtained, it is becoming increasingly difficult and costly.

Moreover, *Aeneolamia* is now being recognised as a serious pest in other areas, *e.g.*, Venezuela, British Honduras, and particularly Mexico—not only of sugar cane, but also of pasture grasses. Here not only does the question of resistance enter the picture, but also with the pasture grasses the prohibitive costs of chemical treatment, and toxicity to mammals have to be considered.

Here again, although the prospects are not encouraging, attention is being turned again to the possibilities of biological control—and our Institute has not only carried out a survey in Mexico of natural enemies, but has considered, in the light of modern knowledge and techniques, the possible more effective use of green muscardine fungus and of a parasitic Mermithid worm.

This leads naturally to a consideration of two further developments in biological control, that of the use of insect pathogens and a consideration of general ecology or biocoenotics, both of which have received increasing attention in recent years.

Insect pathology is usually considered as a separate branch of entomology, but since infectious diseases of any kind are quite obviously an integral part of the biological or natural control of insect populations, this particular aspect of insect pathology merges into biological control. Work on parasites and predators should certainly be complemented by work on pathogenic micro-organisms of all types. The recognition of the importance of this aspect of insect control was indicated by the convening of the First International Congress of Insect Pathology and Biological Control in Prague in August 1958, where a number of these matters were discussed.

Scientific advances in this field in the past few years have been rapid, although from a practical point of view results have been somewhat limited. The most striking developments have been the commercial production of spores of *Bacillus thuringiensis* for use as an insecticide—with the advantages that it is non-toxic to mammals, and also to parasites and predators. It is, however, non-persistent and comparatively expensive. Other developments of interest are the utilisation in spray form of suspensions of virus effective against some pests of crucifers, etc. and the recent apparently promising trial of the use of a parasitic fungus, *Coelomomyces*, against tree-hole mosquitos in the Tokelau Islands in the Pacific. This field will undoubtedly develop increasingly in the next few years, as may that of the use of parasitic nematodes.

The obvious inseparability of biological control by predators and parasites and by insect pathogens—including viruses, bacteria, fungi and nematodes—leads us to a broader concept of biological control, that is the consideration of all the natural enemies of a pest species (and the same applies in general to weeds as well as to insects) in relation to other species, related and not, in the same general environment, and the various interactions between parasites and predators of a given species and facultative or obligatory secondary hosts which may be available or necessary at different times during the annual life cycles. Detailed studies of the ecology or biocoenotics of a given pest, both in the country of origin and the country of introduction—where this has occurred, will obviously be of great value in selecting suitable biological control agents, in understanding the causes of the failure of various promising introductions, and, too, in assessing more accurately the possibilities of successful biological control.

A further interesting field which has been developed more intensively of recent years, particularly in Canada, is that of the assessment of the effect of individual species of parasites and predators on insect populations. Attempts are being made to obtain mathematical expressions from sequential samples of field data showing the effect of biological agents on populations of indigenous insects. In many cases in the past it has been assumed that these agents must be exerting some degree of control, but for some it is now possible to give definite values to their effects, and it may prove that some biological control agents which do not give spectacular results are nevertheless exerting considerable control.

Another aspect of biological control which is now being investigated more fully is that of the application of genetical principles to this field. It has long been realised that in nature there is usually considerable genetic variation in a given population of a parasite or a predator, and that in addition there is considerable geographical variation in many species. More attention is now being paid to the means of utilising this variation in biological control work by manipulation of these differences, in the laboratory and in the field, to produce parasite and predator material more effective in a given environment or against a particular pest. This seems, within certain limitations, to have very interesting possibilities.

Having discussed these general trends briefly I would now turn to the Commonwealth Institute of Biological Control in particular, and here developments may be divided into entomological and administrative, although naturally these two are not completely separable.

With regard to the former our work has naturally been influenced by general trends. I would say, however, at the outset, since I know the question will be one of the first to be raised, that we have not as yet been able to enter the field of insect pathology. An advertisement for a post of insect pathologist on our staff brought not a single reply. This does not mean, of course, that we are not on the look-out continuously for possibly useful micro-organisms in connection with projects assigned to us, but we have at present to rely on other organisations to assess the value and potentialities of these. It is hoped that in due course we shall be able to develop this aspect of biological control within the Institute.

We have in the past quinquennium been requested to investigate the possibilities of biological control in connection with seventy-two projects for twenty-six countries. Many of these projects are of a long-term investigational nature and are still continuing, others consisted of the collection or breeding and shipment of well-known parasites or predators for liberation against some specific pest.

It is not necessary here to give details of this work which has resulted in the publication of eighty-five papers dealing with various aspects of the work, and the shipment of some 1,650 consignments totalling about a million and a half beneficial insects (and birds) to twenty-six countries for release against thirty-five pest species. The successes achieved during this time might, however, be of interest.

Following three years' detailed investigations in Italy by staff of our European Station parasites were successfully established in New Zealand in 1957 against the oak leaf-miner, *Lithocolletis messaniella*, which was first recorded in New Zealand in 1951. Extremely good control has been obtained very quickly as a result of this, and the leaf-miner is no longer of pest status. At the West Indian Station investigations into insects attacking the now very widespread tropical weed *Elephantopus mollis* for Fiji resulted in the introduction of a flower-and-seed attacking Tephritid, *Tetraeuaresta obscuriventris*. This has become successfully established, and I saw it extremely abundantly in Viti Levu in October 1959. No assessment has yet been made as to its effect on seed production and the abundance of the weed, but it looks promising.

During a visit to the island of Nevis in 1957 the economic position of several species of *Opuntia* was discussed—since they render comparatively useless large areas of potential pasture. As a result *Cactoblastis cactorum* was successfully introduced in 1957–58. Most recent reports indicate that control of several of the most noxious species of cactus has been most successful, and that consideration is being given to the spread of *Cactoblastis* to other, similarly plagued, islands of the Leeward group.

In 1957 the citrus black-fly, *Aleurocanthus woglumi*, was recorded for the first time from the Seychelles, and immediately we were requested to supply parasites and/or predators. *Eretmocerus serius* was obtained by our West Indian Station from Jamaica and established in the Seychelles, giving complete control of the black-fly.

Aspidiotus destructor, the coconut scale, was accidentally introduced into the island of Principe, Portuguese West Africa, in 1952 and by 1955 was extremely serious, the copra production of the island eventually dropping to about 30 per cent. of normal. The Coccinellid, *Cryptognatha nodiceps*, was established there from material sent from the West Indian Station, and within a short time extremely effective control was obtained. Copra production is now back to normal (an economic benefit of some £80,000 p.a.).

A number of predators have been successfully established in Canada in attempts to control *Adelges piceae*. It is too early as yet to say to what extent any of these will be effective, and our efforts against this pest are still continuing, particularly as there are now outbreaks of *Adelges* in the west of Canada as well as the east, and it is possible that the climatic differences between the two general areas will affect the establishment of different predator species. Similar inconclusive results have followed the establishment of parasites in Canada against the larch sawfly, *Pristophora erichsoni*, the pine shoot moth, *Rhyacionia buoliana*, and the winter moth, *Operophtera brumata*, and these projects are continuing.

I hope that at the next Conference I shall be able to describe additional definite successes resulting from work being carried out at the present time. This list of successes is naturally small compared with the number of projects undertaken, but this is to be expected, particularly when it is remembered how little actual research or investigation is carried out in connection with many of the projects assigned to us.

It might perhaps be suggested that the results obtained are too infrequent to warrant the continuation of work in this field. However, in some cases we do not, in fact, hear until many years later whether our efforts have been successful, nor to what extent. Also it is often difficult, as in the case of the oak leaf-miner in New Zealand, and with forest pests in Canada, to give any estimate of the actual economic value of the degree of control obtained. It is unfortunately only rarely, as in the case of the control of the coconut scale in Principe, that it is possible to obtain an accurate estimate of the economic value of biological control. However, I think it is obvious from this one example that the economic returns from expenditure on biological control can be enormous. Unfortunately they cannot be guaranteed in every case, but with more detailed knowledge of the relationships of natural enemies to their hosts assessment of possibilities with any particular problem should be more feasible. It should also, I think, be pointed out that, compared with the expenditures on chemical insecticides and herbicides and other methods of control used against many pests, the amount of funds invested in biological control investigations is ludicrously small. Numerous examples of this could be cited, but many are no doubt familiar to most entomologists.

Research work in the Institute has been carried out along several lines. At the Californian Station work has been concentrated particularly on scale insects and mealybugs, and interesting studies have been made on host/parasite relations. At the European Station work has tended to be more along the lines of ecological studies aimed at a better understanding of the role of natural enemies in relation to their biocoenose, as mentioned above. Work on *Adelges* spp. along these lines has been carried out and published, and investigations are now being undertaken similarly with the complex associated with the larch sawfly in Europe.

At the West Indian Station investigations have followed the more usual lines of study—life histories of parasites and predators in relation to their hosts, also general surveys in the area, and more recently investigations of host preferences, and genetical variation amongst a number of parasite species.

Both the Indian and Pakistan Stations have been opened only since 1958 but their work is developing rapidly. Surveys of parasites and predators of various species have been made, and particularly interesting are the studies, begun last year, of the natural enemies of *Adelges* spp. Search has been made over an extensive area of the Himalayas following the discovery of *Adelges* sp. in the general area of Kashmir. The situation with regard to the populations of the pest and its natural enemies is very different from that occurring in Europe and should prove very interesting. An exploratory expedition to the comparatively remote area of Sikkim farther to the east has also produced material of possible value in connection with control of *Adelges*. Work at both the Indian and Pakistan Stations is developing on the investigation of the possibilities of biological control of various graminaceous moth-borers. This is a most important field which merits considerable attention.

In addition it has been necessary in many cases to carry out systematic work on groups of parasites in which we have been interested in connection with projects, and for which accurate determinations have been difficult to obtain. This has been done particularly at the European Station—Tachinidae, Chalcidoidea and Proctotrupoidea, and at Trinidad—Encyrtidae.

Work on the Parasite Catalogue has been considerably increased in the past year, the whole operation having been transferred from Canada to the European Station. The first Part of Section 3 should soon be in print, and within a comparatively short time it should be possible to produce the supplementary volumes bringing the Catalogue in its present form up to date. In addition numbers of the earlier volumes with added errata have been reprinted in the past eighteen months.

Since my appointment as Director in July 1958, I have made two extensive familiarisation tours—one to Pakistan, India, Ceylon, Malaya, New Guinea, Australia, New Zealand and Fiji, and the other to the East African territories, Zanzibar, South Africa, Nigeria, The Gambia and Sierra Leone. At the time of writing (March 1960) the African tour has not yet been started. These have, I feel, been extremely useful in enabling me to discuss with entomologists and other officials in the different countries their various entomological problems, in many cases to see these in the field, and to assess the possibilities of biological control. In addition the possibilities of obtaining useful material *from* these various areas was investigated. As a result of these tours there has been, I think, a considerable increase in interest in the more extensive use of our Institute in all areas visited.

From an administrative point of view there are a number of matters affecting the Commonwealth Institute of Biological Control which should be of interest to this Conference.

I would in the first place like to pay a tribute to Dr. W. R. Thompson, F.R.S., who retired at the end of June 1958. It was through his efforts that this Institute developed from its small beginnings as the Farnham House Laboratory of the Imperial Bureau of Entomology (now the Commonwealth Institute of Entomology) in 1928 to its present fairly widespread organisation, and I know that Dr. Thompson's retirement—albeit to active entomology—will be felt as a loss by all Commonwealth entomologists.

During this past five years the scope of the Institute work has increased considerably with the development, by means of Canadian Colombo Plan funds, of two additional stations, one in India and the other in Pakistan. These were developed and built under the supervision of Mr. W. F. Sellers, formerly Assistant Director of the Institute, and the present laboratories and the extent of the projects developing at each are a measure of recognition of his work. In this connection too I would like to record my appreciation of the untiring efforts of Mr. H. L. Trueman, the Commonwealth Agricultural Bureaux Liaison Officer in Canada, who has helped so much, both in connection with Colombo Plan matters and with the general affairs of the Institute in Canada.

The station in India is in the south centre of the country at Bangalore, within comparatively easy access of a variety of climatic zones, and that in Pakistan is at Rawalpindi in the northern part of West Pakistan, close to the foothills of the Himalayas, and from it a wide range of diverse cultivation can be studied—from the hot, dry plains to the alpine areas to the north. A number of projects have already been assigned to these stations, and they will, it is certain, prove extremely useful additions to the Institute's strength, not only being able to carry out biological control work in their respective countries, but also able to tap largely unexploited material of beneficial species for use elsewhere.

There has also been developed during recent years, and particularly in the last two, a far greater measure of international co-operation in the field of biological control. It has been, and will be, very much to the advantage of Commonwealth countries if every encouragement can be given in this regard. Working arrangements have already been made to obtain useful material for Canada from Czechoslovakia, and more recently from Russia, Poland, and Bulgaria, and this can certainly be extended in the future on an exchange basis. Moreover close contact is maintained with the United States Department of Agriculture, and we have recently been able to obtain very easily for them material of several parasites which they needed (naturally, costs of this have been paid by the United States Department of Agriculture). There are proposals now under consideration for the utilisation at our Indian and Pakistan Stations of United States blocked rupee funds on several biological control projects of interest not only to the U.S.A. but to a number of Commonwealth countries. Last year we undertook work for Mexico (financed by the Rockefeller Foundation) on *Aeneolamia postica*, carrying out a survey of natural enemies which might have indicated material of interest to Trinidad and British Guiana. Tentative working arrangements have been made with Hawaiian biological control workers and those of the Citrus Experiment Station in California which will, I am sure, be mutually beneficial, and make available very economically increasing numbers of possibly useful species for trial in different areas.

There has in the past appeared to be in a number of Commonwealth countries a lack of information regarding the activities of the Institute and the work being carried out at our various stations. Every effort will be made to remedy this, both by means of reports on the various projects assigned to us during the year, and information as to material or beneficial species which is readily available at any particular time. It is also hoped, by the increased mobility of both the Director and other staff, that the services of the Institute may be more widely known, that they will be utilized to the fullest extent, and that no possibility of trial of a potentially useful species will be lost in any area because of lack of information.

In addition we have started a system of producing memoranda on the present possibilities of the biological control of certain pests which are of interest to several Commonwealth areas. The object of these is to bring to the notice of the appropriate authorities information as to what has been done with any particular pest in the past, results achieved, etc., and what further work on biological control might be considered worth while. It is hoped that these memoranda may encourage various countries to develop biological control projects, and, moreover, that it may be possible in a number of instances to arrange that a project of interest to several areas be carried out on a co-operative basis—each country providing a part of the necessary total funds, with an obvious overall economy. Such memoranda have already been prepared on several pests including the potato tuber moth, *Gnorimoschema operculella*, Californian red scale, *Aonidiella aurantii*, the mealybugs, *Pseudococcus gahani* and *P. maritimus*, the pear-slug, *Caliroa cerasi*, the vegetable weevil, *Listroderes obliquus*, etc., and an important one on the codling moth is in course of preparation.

There has been every indication from discussions held during my recent tours, and also because of increased attention being paid at present to alternatives to chemical methods of insect (or weed) control, that there will be a steady expansion of our work in the next few years. I hope that this will be gradual rather than " explosive " and that any increase in the size of the Institute will be slow, and related to the demand for our services. In the past we have in general awaited requests for projects to be sent from Commonwealth countries, and have then undertaken the investigations, etc., demanded. I think that we should in addition try to suggest, partly by the memoranda mentioned already, problems in which biological control and the services of the Institute might produce successful results in various areas, and in this way increase the definite economic value of biological control in the Commonwealth.

In this connection, too, I would refer to the recommendation of the Commonwealth Agricultural Bureaux Review Conference, 1955, that further consideration should be given to the establishment of a station of our Institute in East Africa. There have been very definite requests from the East African territories for this several times in the past, and in March and April of this year during my tour of these countries this was fully discussed. I am of the opinion that a station in this general area is most desirable, and it should be located in a central position, with easy air transport facilities to various ecologically different areas, and within a comparatively short distance of a number of different climatic areas. I would suggest that this Conference recommends the establishment of this East African Station—for which a number of promising projects (with appropriate finance) have already been requested.

This present expansion in our work, and foreseeable greater increase in the near future, will inevitably require additional staff, since our present staff is more than fully occupied with current projects. A number of projects must be tackled in South America, and Dr. Lloyd from the Californian Station will possibly be transferred to Chile towards the end of the year. To take his place in California we hope to appoint an additional entomologist.

We are handicapped in both India and Pakistan by lack of trained entomologists on the staff, and although it might be possible to second suitable officers from the Plant Protection Departments of the respective Governments conditions of service in the Institute in regard to fringe benefits are not sufficiently attractive for officers to want to make such a move. This situation will be helped to a certain extent by moving well-trained staff temporarily from our European Station to Pakistan and India to assist in some of the projects at present requested, my intention being to keep the European staff up to strength with the appointment of additional, younger, officers who can undergo a period of training there before being permanently appointed to a station.

At least one additional permanent officer is necessary at each of the Indian and Pakistan Stations, an additional two if an East African Station is developed, and also an insect pathologist if one can be obtained. The response to a recent advertisement indicates that recruiting of staff interested in biological control and willing to work under the conditions offered by the Institute will be difficult.

It should be stressed that the conditions of service of the Commonwealth Institute of Biological Control are very different from those of any of the other Institutes and Bureaux, and that although in some cases the salaries offered appear generous this is often more than offset by the lack of other benefits—home leave with passages paid, provision of housing, children's allowances, medical benefits, etc., which are normally received by officers working in the tropics or in certain other areas. I have already made definite proposals in this regard in connection with our officer at the West Indian Station. I think that it will be quite impossible to contemplate opening an East African Station unless these factors are taken into consideration. The whole matter of conditions of service of officers serving abroad at our Stations should be considered by this Conference and suitable recommendations made, so that action can be taken on this without undue delay.

I might mention the accommodation of our Headquarters and five Stations. Headquarters at Ottawa are in quite adequate space, to date very generously provided free of charge by the Government of Canada. Our Californian Station at Fontana has its own laboratory building and grounds belonging to the Institute. The Stations in India and Pakistan comprise adequate grounds and excellent buildings specifically designed for this purpose, and constructed with the aid of Canadian Colombo Plan funds; the property of the respective Governments, they are leased to us at a token annual rental. Accommodation in Switzerland is less satisfactory, since our European Station is housed on the second floor of an old building, and provision of suitable land, insectaries, etc., is difficult. The laboratory facilities are quite adequate, but it seems possible, and it would certainly be preferable, that arrangements could be made to have a building constructed by a local contractor on suitable grounds at Delemont and leased to us.

Our West Indian Station is the worst off in this regard. We have been very generously housed by the Imperial College of Tropical Agriculture since the Station was started in 1946, and it is only for the past seven years that, by mutual agreement, rent has been paid for the space occupied. Although the College has made every effort to give us the accommodation we need this has always, quite naturally, been subject to the requirements of the College itself, and at times things have been rather difficult and our quarters cramped. At present, with the administrative changes at Imperial College of Tropical Agriculture we are, of course, uncertain as to our future position in this regard. It would seem a great pity if this mutually advantageous association were to be disrupted, and we are hoping that it may be possible to obtain funds for our own building to be constructed in association with a number of new science buildings at Imperial College of Tropical Agriculture, or alternatively that very definite arrangements might be made for allotting us adequate space in one of these new buildings. The former would obviously be preferable.

This leads to the question of the location of Headquarters of the Institute, which is an item on the agenda for discussion. As a result of my visits to our Stations I am convinced that the ideal would be that the Director should move around from one station to another spending three to four months, or longer if warranted, at each, becoming fully conversant on the spot with the organisation of each. This, however, would hardly be practicable. As an alternative I think that Headquarters should be moved to an area where active Institute work is in progress, so that the Director, in addition to administration, could carry out some entomological investigations, and also permit of more freedom of movement of the officer(s) at that particular Station. From this Station fairly frequent visits of at least three months each should be paid to the other Stations. This might be somewhat gruelling, but I am sure that the results achieved would be worth while. The most suitable location for this would be the West Indian Station, where I have already been. It has been suggested as an alternative that, if we do in fact develop a Station in East Africa, this would be equally suitable.

Whilst I think that it is much to be preferred that Headquarters should be in an area where active Commonwealth Institute of Biological Control work is being carried out, I do *not* think that apart from this the actual location of Headquarters is important. Headquarters of our Institute, unlike the other Institutes and Bureaux, comprises virtually only a secretarial and accounting staff and this work can be done anywhere.

It has been argued that Headquarters should be moved back to the United Kingdom, on the grounds that with Headquarters in Ottawa or elsewhere, the administration of this Institute is more difficult than that of the other Commonwealth Agricultural Bureaux units. These difficulties do not stem from the location of Headquarters, but from the fact that we have in addition Stations in five countries and officers working in other different areas.

It has also been argued that a move back to the United Kingdom would entail a considerable financial saving. I do not think that this is so since wherever Headquarters is located our salaries (with the possible exception of that of the Director) would have to remain at the same levels, since apart from certain disparities between our own and comparable " local " salaries at the West Indies and Californian Stations our scales are reasonable for the qualifications and duties of the scientific staff. There would be a certain saving on the salaries of office staff but that would be very little. Rental of office space in England would be a consideration and this would not be incurred if Headquarters were at an already existing Station.

The proximity of representatives of all Commonwealth countries in both Ottawa and London has been put forward as an advantage, but this certainly seems to be a theoretical rather than a practical one, as is the question of the advantages of being near to Commonwealth Agricultural Bureaux Headquarters. In fact I shall undoubtedly, for both official and personal reasons, be in the United Kingdom quite often wherever Headquarters are located, with adequate opportunities to discuss any necessary matters with the Secretary and/or Council members.

I would suggest therefore that Headquarters should be moved to the West Indian Station. This move I feel would receive the support of the Federal Government of the West Indies, and also would be *approved* by a number of entomologists on purely technical grounds.

F. J. Simmonds, *Director*

APPENDIX III

PROCEEDINGS OF COMMITTEES

1. The Committee, constituted as shown on p. 7, held meetings on 6th, 8th and 15th July.

2. The agenda comprised the following items:—

- (i) A memorandum by the Director of the Commonwealth Institute of Entomology on the work of the Institute, covering the period 1954–1960 (Appendix I).
- (ii) A memorandum by the Director of the Commonwealth Institute of Biological Control on the organisation and work of the Institute (Appendix II).
- (iii) A memorandum by Dr. M. L. Roonwal (India) on the desirability of establishing Regional Identification Centres.
- (iv) Other business.

Action taken on a number of resolutions of the last Conference was reported in the memoranda of the Directors. The only subject included under item (iv) of the agenda was that of arrangements for future Commonwealth entomological conferences.

3. The Sub-committee appointed to consider the work of the Commonwealth Institute of Biological Control was constituted as shown on p. 7 and reported to the main Committee at its final meeting. The recommendations of the Committee were submitted to the final plenary session of the Conference and incorporated in the Conclusions and Resolutions that were adopted (pp. 9–11). A summary of the discussions that took place in committee is given in the following paragraphs (4–34).

The Identification Service

4. When the Committee considered the Director's report on the Identification Service, interest centred on the practicability of carrying to species level a greater proportion of identifications in certain groups of particular economic importance, notably the parasitic Hymenoptera and the mites. It was explained that the frequent inability of specialists to assign material to known species reflects mainly the taxonomic position in such groups, that the problem is part of a world-wide one, in the attack on which the Institute plays an important part, but that any increase in the amount of taxonomic research undertaken by the Institute would necessarily require more staff if the routine identification work was not to suffer. Discussion centred on the extent to which the existing staff was able to deal with routine identifications and also engage in revisionary work. The Committee considered that, although routine identification work should always have precedence, taxonomic research was indispensable to progress, that it was proper that such work should be undertaken by Institute staff, who were essentially well qualified to do so, and that an expansion of staff was accordingly warranted (Resolution 7).

5. The Committee was informed of the increasing difficulty that is likely to be met in accommodating further staff in the Department of Entomology at the British Museum (Natural History). Recognising the need that was stressed by the Sixth Commonwealth Entomological Conference for an expansion of taxonomic research on a broad front, requiring contributions from many sources, including taxonomists on the staff of the Museum and others for whom temporary facilities for study at the Museum were essential, the Committee wished to record its earnest hope that endeavours to increase output in insect taxonomy will not be hampered by shortage of accommodation and of working space in the Department of Entomology at the Museum (Resolution 11).

The Review of Applied Entomology

6. The Committee considered the present abstracting policy in relation to the need for adequate coverage of an expanding literature. The fear was expressed that unless steps could be taken to deal with the increase in the literature, a progressive reduction in coverage was inevitable. A diversity of opinions was expressed about a number of possible ways of meeting the situation, including those of noticing a greater proportion of papers by title only, by not abstracting papers in the most widely read journals in order to deal with more in the less familiar, by using contributions from outside abstractors, and by supplying the address of the author of the paper abstracted so as to facilitate direct reference to him. It was agreed that the form and content of the *Review* abstracts are greatly appreciated by Commonwealth entomologists and that the difficulty of coping with an increasing literature should not be met by making radical changes in presentation of the *Review*, but by the appointment of additional staff (Resolution 4).

7. The difficulty of recruiting and retaining abstracting staff was also discussed. It was pointed out that while there were several reasons for the resignation of staff, chief among them were a desire for a financially more attractive post and a desire for more congenial work. It was recognised, in discussion, that provision of higher salaries for posts in the abstracting service would not remove all the reasons for leaving, but it was considered that it would be of help, and in addition would attract applicants of the desired standard (Resolution 4).

8. The views of the Committee were sought on the nature of the annual indexes to the *Review* and on what might be regarded as an acceptable delay in their publication. It was stressed that the form of the index incorporated features that expedite the task of tracing information, and that enhance the value of the *Review* as a permanent work of reference. The view was expressed that a lapse of up to a year would not be unacceptable, and that one of between five and eight months, such as was the rule before the war, would be sufficiently short. It was generally agreed that the standard of the indexes should not be lowered for the sake of accelerating publication (Resolution 5).

Zoological Record, Part Insecta

9. The Director outlined the historical background of the Institute's association with this publication and explained that its compilation was an integral part of the machinery for covering the literature. Although the *Insecta* was not a Commonwealth Agricultural Bureaux publication, its preparation was in fact most intimately associated with almost all aspects of the work of the Institute. The Committee appreciated the effectiveness of the present arrangements, and indicated that additional support should be sought for the compilation of *Insecta* (Resolution 6).

List of Current Research Projects in Economic Entomology

10. The Committee noted the information given in paragraph 38 of the memorandum on the work of the Institute and concluded that the original proposal had been properly carried out as far as the Institute was concerned, and had proved to be not worth the effort involved. It was generally agreed that the Institute should no longer be expected to carry on this task (Resolution 9).

A Directory of Institutions Engaged in Research in Economic Entomology

11. The Committee thought that the bulk of the information that such a directory would be expected to provide could already be found in the *List of Research Workers in Agriculture, Animal Health, and Forestry* issued by the Commonwealth Agricultural Bureaux. There appeared to be insufficient justification for requiring the Institute to compile and maintain such a directory, particularly as it would inevitably interfere with its normal duties (Resolution 10).

Reviews of Work on Economic Entomology in the Commonwealth

12. The question of the utility of the Reviews of Work was discussed. It was stated that opinion in Australia amongst entomologists concerned in the preparation of the review

from that country was that this was of doubtful value; it tended merely to cover work that had been more adequately presented elsewhere, and there was, in any case, some feeling that separate reports prepared by entomologists in the different States or Institutions would be preferable to a combined review prepared centrally. Other criticisms were that the reviews were out of date before they appeared, and that they could not be used as a guide as the names and addresses of those whose work was mentioned were usually not given. Discussion nevertheless showed that most members of the Committee thought the reviews were of interest, and some that they were of practical value; there was general agreement that they should be retained, but that they should be briefer, and more uniform in presentation (Resolution 8).

Phyto-Sanitary Co-operation in Africa

13. The developments in this field which had occurred since the last Conference were outlined by the Director. The Committee were greatly impressed by the success that has been achieved by the Inter-African Phyto-Sanitary Commission, since its formal establishment in 1956, in implementing the recommendations of the Commonwealth Entomological Conference of 1948. It was remarked that the speed with which action had been taken reflected the importance that was attached to the subject in Africa. The Committee agreed that their satisfaction should be appropriately expressed (Resolution 12).

Biological Control

14. The Sub-committee appointed to consider the memorandum of the Director of the Commonwealth Institute of Biological Control met on 11th July and submitted its findings to the main committee on 15th July.

15. The Sub-committee first noted the actions taken to implement resolutions of the 1954 Conference.

16. They next considered to what extent it was desirable that officers of the Commonwealth Institute of Biological Control should engage in research. The view was expressed that research is inseparable from the work of the C.I.B.C., and should be carried out both in the collection and the liberation areas, but only such research should be undertaken as is necessary to the practical end in view; it would be undesirable, for instance, to conduct mathematical studies on population dynamics. It was agreed that ecological investigations regarding a parasite's requirements in its native habitat, designed to supply a background of data prior to its introduction into another territory, were desirable, and one or two members felt that such work might advantageously be pursued by C.I.B.C. staff in greater detail than hitherto. However, local entomologists, if available, should be responsible for studies on introduced species after liberation. The extent of any research in connection with a project should be left to agreement between the two contracting parties.

17. The Sub-committee was asked to consider whether it was appropriate for the Institute of Biological Control to engage in work on insect pathogens. The Director had indicated in his memorandum that the appointment of an insect pathologist had been approved, but so far he had been unable to recruit a suitable officer. In reply to questions the Director stated that there was a potential project ready to hand in European investigations on behalf of Canadian forest entomology; that he thought that fundamental work in this field should be undertaken only in connection with specific projects; and that, when making an appointment, he would prefer to select a bacteriologist. The Sub-committee thought serious consideration should be given to building up this branch of biological control, which fell naturally within the scope of the Institute's work, and recommended that the Director report progress to the next Conference (Resolution 22).

18. On the subject of travel by the Director, several Committee members said that they welcomed his visits for on-the-spot discussions, and thought it important that he should see problems at first hand and keep in close contact with laboratories in different parts of the world. Apart from visiting Commonwealth territories in order to discuss their problems, he should visit C.I.B.C. stations to direct their work. It was suggested that from an entomological standpoint it was more desirable that the Director should travel than that he should be permanently stationed at a headquarters office. The point was raised, however,

that if the headquarters were in London the Director would be more readily accessible, and in consequence would have less need for travel. It was agreed that if it was accepted that the most appropriate way for the Director to carry out his duties was by frequent travel, it would not much matter where the headquarters were located (Resolutions 17 and 18).

19. The Sub-committee noted with satisfaction that negotiations had been completed for the establishment of C.I.B.C. substations in India and Pakistan and these stations had come into operation. It was considered that their progress to date had justified the recommendation for their establishment (Resolution 15).

20. The progress of the Parasite Catalogue was considered next. The Director indicated that he wished to see the present catalogue completed as quickly as possible, and a second catalogue undertaken, in this case with critical notes. In the discussion that followed it was asked whether it was worth while completing the existing catalogue, which covered the literature only up to 1936, how the work of compilation was fitted in with the other duties of the staff, and what would be the main features of the critical catalogue. The Director maintained that it would be worth while to round off the existing catalogue, and estimated that this might be done by the time of the next Conference. The work was carried out as a winter occupation in the European station. In the critical catalogue, parasites would probably be assigned to one of three categories—recognised parasites of major importance, less important parasites but of reliable status, and dubious records. In further discussion it was thought that the compilation might prove complex, and, as its coverage would not be limited to records published in the *Review of Applied Entomology*, it would almost inevitably prove an onerous task. On this account it should be considered very carefully before a beginning was made. It was recommended that Commonwealth entomologists should be consulted about the form that the catalogue should take (Resolution 23).

21. Consideration was given to the desirability of establishing biological-control projects on a cooperative basis. The Director said that he had suggested that funds should be available to enable the Institute to take the initiative in such investigations. In reply to a query, the Director explained that, broadly speaking, when a project of possible benefit to several territories was undertaken on behalf of one, the others were notified; it was pointed out that co-operation could not be enforced. It was agreed that co-operation was calculated to allow an investigation greater scope, and that it was proper for the C.I.B.C. to try to arrange such co-operation (Resolution 19).

22. On the question of international collaboration, the Director explained that projects on behalf of foreign countries could be authorised by the C.A.B. Executive Council, to be undertaken in so far as they did not clash with Commonwealth work. Problems were often of regional interest, and even if investigated primarily on behalf of a foreign government, could be expected also to yield results of value to Commonwealth territories. The Committee endorsed the present policy (Resolution 20).

23. The position regarding the proposed substation in East Africa was reviewed. It was confirmed that laboratory facilities had been offered, and that it would be possible to site a station in Uganda, where opportunities for collecting were good, or at Nairobi, on a major air-route. The present difficulty was that of capital for establishment. Only one half of the £18,000 estimated for the first three years could be raised from local sources. There were several local problems that could form the basis for projects. The Director explained that the salaries of the permanent staff would be paid for by C.I.B.C. funds, and that project funds would cover the additional costs for each project. The Committee endorsed the recommendation embodied in Resolution 10 of the Sixth Commonwealth Entomological Conference, 1954, regarding the establishment of a substation in East Africa (Resolution 14).

24. The proposals for an increase in staff were explained by the Director, and it was agreed that three more appointments were desirable in addition to the twelve already on the establishment (Resolution 25).

25. Consideration was given to the desirability of the Institute's acquiring its own premises for housing the European and West Indian stations. The Director believed that in both territories work would continue for a long time, that possession of its own buildings would give stability to the organisation in the area, and that outright ownership would entail

fewer administrative difficulties and uncertainties than had been experienced while renting. The proposal was supported (Resolution 16).

26. In discussing the preparation of regional surveys of biological control work in the Commonwealth, attention was drawn to the review of such work in Australia and New Guinea that had recently been issued as a Technical Communication by the C.I.B.C., and it was stated that two reports on biological control problems in Canada were being prepared in that country, one dealing with forest entomology, the other with agriculture. The C.I.B.C. substations in India and Pakistan were compiling reviews for their respective areas, and similar reviews for West Africa and East Africa, for the West Indies and for the Pacific area have been or are due to be discussed by the Director, C.I.B.C., with the appropriate officers. It was asked whether each territory was expected to assume responsibility for reviewing the biological control work within its own bounds; the Director replied that the view had been expressed that such work could be done most efficiently by the person on the spot. The Sub-committee agreed that such reviews should be completed as soon as possible (Resolution 24).

The Desirability of Establishing Regional Identification Centres

27. The Committee considered a memorandum by Dr. M. L. Roonwal (India) in which it was suggested that reference collections of insects should be built up in Commonwealth countries, and should be used for the identification of the more common insects; such collections would be located at Regional Centres, and each such centre would be staffed with local entomologists; such an arrangement could be expected to encourage the development of taxonomic talent, and of insect collections, in the territories concerned, and correspondingly to reduce the amount of work at present done by the Commonwealth Institute of Entomology, and to save time and costs of transporting material.

28. Questions were asked about the responsibility of, and the area to be served by, stations of the kind suggested, and the sources from which their staff would be recruited and their funds obtained. The proposer explained that in his conception of the scheme the regional identification Centres should supplement the Commonwealth Institute of Entomology as substations. A regional identification Centre might be concerned with an area that included several countries, not all of which might be members of the Commonwealth. In the case of a regional identification Centre based in India, he did not think that the submission of material from nearby countries would create any special technical difficulty as it would all be from the same zoogeographical region. He had considered that it might be difficult for the C.A.B. organisation to find funds for this purpose, but, as far as a Centre in India was concerned, this would not be the main difficulty since there was a possibility of obtaining funds locally or through the agency of the Colombo Plan. He recognised the current existence of political difficulties, but believed that these would disappear after a few years' experience of the operation of the identification Centre. He considered that the staff should as far as possible be local, and that such staff would probably prove the most economical to maintain. It would be preferable, in his view, for the Commonwealth Institute to establish such Centres, as substations, than, for example, for India to take the initiative by establishing an identification Centre for Indian material with the collaboration of the Institute. The insect material for identification, within the region covered, would first be submitted to the Regional Centre though entomologists would not be prevented from sending material to any place they might prefer.

29. In discussion of the proposal, it was stated on behalf of East Africa that although local entomologists had tentatively considered the Coryndon Museum as a possible central repository for East African collections, there was no money available locally for curatorial and specialist staff.

30. Some support for the idea in principle came from West Africa, although fears were expressed, on some hands, that practical difficulties at the present time might hinder the effectiveness of a regional identification Centre established in that area.

31. It was stated that Canada, South Africa, Australia and New Zealand had for many years maintained their own reference collections, and that these territories would themselves

expect to arrange and finance, as a straightforward matter of internal administration, any expansion that they might feel necessary.

32. The Director of the Commonwealth Institute of Entomology commented that the financial resources of the Institute were barely sufficient for the present needs of the identification service, which was maintained with the minimum of staff. One of the objects of the identification service had been to enable the territories it served to build up their own reference collections of authentically named material, and to this extent the aim of the present proposal was one that the Institute warmly supported and had consistently tried to foster. But if the proposed regional substations were to be set up and financed from the resources now allocated to the Institute, it would be impossible for the latter to carry on effectively.

33. Several members of the Committee felt unable to foresee all the possible implications of the proposal without longer consideration and expressly preferred to withhold comment until they had had opportunity to obtain the view of colleagues in their own territories. It was agreed that delegates should take the relevant Conference papers back for discussion in their respective countries, and that on the basis of such discussions comments should be sent to the Director of the Commonwealth Institute of Entomology, to form the basis of a memorandum for circulation prior to, and consideration at, the next Commonwealth Entomological Conference.

Future Commonwealth Entomological Conferences

34. The Director, Commonwealth Institute of Entomology, suggested that the Committee might usefully consider the possible advantage, in the event of a decision to hold the Twelfth International Congress of Entomology in London in 1964, of holding the next Commonwealth Entomological Conference in London immediately before the International Congress. Such an arrangement would be calculated to save much travel by entomologists working overseas, and to permit at least some of them to attend both where otherwise they would be able to attend only one, and would still ensure that there was not too long an interval between the Commonwealth Entomological Conference and the Commonwealth Agricultural Bureaux Review Conference due to be held in 1965. If such an arrangement were made the open sessions of the Congress would replace those of the Commonwealth Entomological Conference and the proceedings of the latter would be restricted to those matters of Commonwealth interest normally dealt with in plenary session and by committees. It was asked whether the Entomological Conference, even if convened when suggested, should not be held in its usual form. In reply it was pointed out that speakers who wished to present communications would have an opportunity of doing so at the scientific sessions of the Congress and that the business meetings of the Conference would follow their present lines. After further discussion a recommendation was agreed in a form that would enable definite proposals to be made after the venue of the Twelfth International Congress of Entomology became known (Resolution 26).

crops treated at home and overseas have greatly increased. Very few agricultural insect pests are now able to resist control by one or other of the available materials, and the gains to agriculture, especially in some countries overseas, have been immense. Before proceeding to a review of the new compounds, brief references should be made to nomenclature and mammalian toxicities.

Nomenclature

At the Fifth Conference in 1948, a committee was set up to promote the adoption, internationally, of simple coined names for the active ingredients of proprietary products. Action followed quickly; in 1949, a British Standards Institution committee was formed which has since published lists of common names for many insecticides, acaricides, fungicides, herbicides and rodenticides (1957, 1959). The committee works closely with the International Organisation for Standardisation (ISO) whose function is to translate national standards into accepted international standards. The materials I shall refer to this morning are those that have become established since the last Conference, or that are considered by the BSI or ISO nomenclature committees to be sufficiently promising to warrant common names.

Hazards to Operators and Consumers

Operators

Some of the older chemicals that are highly toxic to man are still used, and some new chemicals of high toxicity have been developed. Knowledge of their potential hazards is important in deciding what precautions should be taken during spraying operations. To indicate the relative mammalian toxicities of the new chemicals, an arbitrary classification into groups is shown in the Table, based on acute oral L.D.50 values reported from animal tests, usually on the male rat.

	mg./Kg.		mg./Kg.		mg./Kg.
1a	up to 50	2a	100–300	3a	500–1,000
1b	50–100	2b	300–500	3b	over 1,000

The acute oral L.D.50 value from animal tests should not be used as the sole criterion in assessing toxicity to operators; inhalation and especially skin absorption are important factors and must be considered. A compound may have a high inherent toxicity but may show low skin absorption; on the other hand, a compound of moderate toxicity may penetrate the skin more readily. From field experiences with toxic materials, there is every indication of erring on the safe side if the chemicals in groups 1a and 1b are regarded as potentially dangerous to man if not carefully used, and if those in groups 2a and 2b are regarded as possessing moderate toxicities. The classification suggested by Edson (1958) which is based on laboratory and field data on the properties, hazards and medical histories of spray chemicals shows that the compounds which show acute oral L.D. 50 values of 50 mg./Kg. or less, when tested on the rat, provide the greatest risks to operators. Although difficult to make, dependable distinctions between potentially dangerous and the safer materials are important; at present there is a tendency to regard compounds of moderate toxicity as safe. Dr. Miller this afternoon will explain the regulatory procedure used in this country and will describe the Parts I–IV categories in which potentially dangerous chemicals are placed.

Consumers

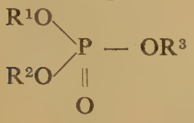
The chief factor inducing a possible hazard is a pronounced persistence on or in plants of a chemical possessing a chronic toxic action. The rate, frequency and method of application, and the natures of the formulation used and of the surface treated, all influence the amount of chemical originally deposited. Weathering and the growth of the crop then reduce the degree of contamination. The final residue, usually expressed as parts per million in the foodstuff, is determined by chemical or bioassay, and such tests have become an important feature of crop protection work. The consumer hazard is then assessed from the toxicological properties of the chemical and the level of contamination found. In this country, maximum rates of application of potentially dangerous chemicals and the minimum periods that must elapse between the last application and harvest have been laid down for the protection of consumers.

The New Chemicals

Organo-phosphorus Compounds

The most significant advances have been made in the organo-phosphorus group; the new compounds are shown in the Table. These are esters of phosphoric acid and its sulphur analogues, and may be classified as follows:

(a) Phosphates



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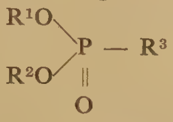

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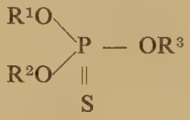

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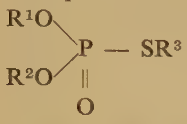

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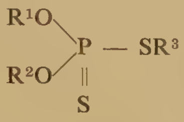

With few exceptions, R^1 and R^2 are methyl or ethyl groups, the major differences between the compounds in any group being accounted for by R^3. Relationships are easily seen; for example, demeton-methyl and thiometon contain identical R^1, R^2 and R^3 groups, but the former is a phosphorothionate and the latter a phosphorothiolothionate.

The compounds are recommended for the control of horticultural pests such as Aphids, mites, caterpillars, scale insects, Thrips and mealybugs. Other phosphorus compounds are proposed for use as nematicides and soil insecticides; diethyl 2,4–dichlorophenyl phosphorothionate of moderate (2a) toxicity to animals, and diethyl 2–pyrazinyl phosphorothionate of high (1a) mammalian toxicity, are examples. Recent compounds developed for aphis control are triazinyl derivatives such as menazon[2] (dimethyl 4,6–diamino–1,3,5-triazin–2yl–methyl phosphorothiolothionate) which show systemic action.

An interesting development is the use of coumaphos[2] (diethyl 3–chloro–4–methyl–7–coumarinyl phosphorothionate; Co–Ral), phenchlorphos[2] (dimethyl 2,4,5–trichlorophenyl phosphorothionate; Trolene, ronnel) and methyl 4–*tert*butyl–2–chlorophenylmethyl phosphoroamidate (Ruelene) for the control of cattle parasites. Another phosphorus compound, dimethyl 2,2,2–trichloro–1–*n*–butyryloxyethyl phosphonate (butonate), is proposed for use against indoor pests.

Halogenated Hydrocarbon Compounds

Comparatively few compounds have appeared in this group. Chlorobenzilate[1,3] (ethyl *pp′*–dichlorobenzilate), fluorbenside[1,3] (p–chlorobenzyl–*p*–fluorophenyl sulphide), 2,2,2–trichloro–1,1–di(*p*–chlorophenyl)ethanol (Kelthane) and tetradifon[3] (2,4,5,4′–tetrachloro-diphenyl sulphone; Tedion) have supplemented the acaricides; all show low mammalian toxicities. 2,2–Dichloro–1,1–di(*p*–ethylphenyl)ethane (ethyl–DDD, Perthane), of low mammalian toxicity (3b), is used for the control of pests of crops and livestock. Chlorthiepin[2] (6,7,8,9,10,10–hexachloro–1,5,5a,6,9,9a–hexahydro–6,9–methano–2,4,3–benzodioxathiapine 3–oxide; Thiodan) shows a contact action against insects and some mites and a moderate mammalian toxicity (2a–1b.). None of these compounds is highly toxic to bees. 1,2–Dibromo–3–chloropropane (Nemagon) is a nematicide and soil fumigant of moderate mammalian toxicity (2a).

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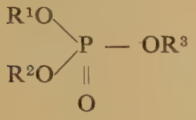

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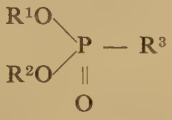

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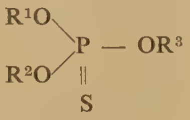

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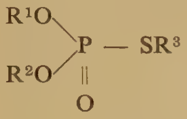

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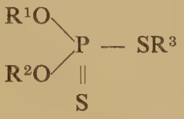

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ORGANO-PHOSPHORUS COMPOUNDS

Common Name	Other Name	R^1, R^2	R^3	Properties	Oral toxicity: minimum period application—harvest
PHOSPHATES	Dibrom Ortho Dibrom	methyl	1,2-dibromo-2,2-dichloroethyl	Contact insecticide. Some acaricidal action. Short persistence.	Moderate, 2b
dichlorvos [1,3]	DDVP	methyl	2,2-dichlorovinyl	Contact insecticide and acaricide. Short persistence.	Moderate to high, 1b
phosmevin [2]	Phosdrin	methyl	2-methoxycarbonyl-1-methylvinyl	Systemic insecticide and acaricide. Quickly broken down in plant.	High, 1a Regulations, Part II 3 days
phosphamidon [1,3]		methyl	2-chloro-2-diethylcarbamoyl-1-methylvinyl	Systemic insecticide and acaricide.	High, 1a Regulations, Part III 3 weeks
PHOSPHONATE trichlorphon [1] trichlorfon [3]	Dipterex	methyl	2,2,2-trichloro-1-hydroxyethyl	Contact insecticide. Moderate persistence on plants. Used in baits indoors.	Moderate to low, 2b-3a 2 weeks
PHOSPHOROTHIONATES fenthion [2] temephos [2]	Baytex	methyl	3-methyl-4-methylthiophenyl	Contact insecticide, agricultural and indoor pests. Residual effect indoors.	Moderate, 2a
	Chlorthion	methyl	3-chloro-4-nitrophenyl	Contact insecticide.	Low, 3b
demeton-methyl [1,3]	Metasystox	methyl	2-ethylthioethyl	Systemic insecticide and acaricide. Isomers demeton-O-methyl [1,3] (thionate) and demeton-S-methyl [1,3] (thiolate)	Moderate, 2a Regulations, Part III 3 weeks

ORGANO-PHOSPHORUS COMPOUNDS (Continued)

Common Name	Other Name	R [1], R [2]	R [3]	Properties	Oral toxicity: minimum period application—harvest
PHOSPHOROTHIONATES diazinon [1,3]	Basudin	ethyl	6-methyl-2-*iso*propyl-4-pyrimidinyl	Contact insecticide, moderate persistence on plants. Used against animal and household pests.	Moderate, 2a 2 weeks
	dicapthon	methyl	2-chloro-4-nitrophenyl	Contact insecticide, residual action.	Moderate, 2b
PHOSPHOROTHIOLATE endothion [1,3]		methyl	5-methoxy-4-pyron-2yl-methyl	Systemic insecticide and acaricide.	High, 1a
PHOSPHOROTHIOLOTHIONATES dimethoate [2]	Rogor	methyl	*N*-methylcarbamoylmethyl	Systemic insecticide and acaricide. Short persistence.	Moderate, 2a-2b 1 week
dioxathion [3]	Delnav	ethyl	1,4-dioxan-2,3-dithiol-S,S-bis	Contact insecticide and acaricide.	Moderate, 2a
	Disyston Dithio-Syston Dithio-demeton	ethyl	2-ethylthioethyl	Systemic insecticide and acaricide. Used for seed treatment.	High, 1a
ethion [1,3]	Nialate	ethyl	methylene-bis	Contact acaricide and insecticide.	Moderate, 2a
malathion [1,3]	Malathon	methyl	1,2-di(ethoxycarbonyl)ethyl	Contact insecticide and acaricide. Short persistence.	Low, 3b 1 week
mecarbam [2]		ethyl	*N*-ethoxycarbonyl-*N*-methylcarbamoylmethyl	Contact insecticide and acaricide.	High, 1a

ORGANO-PHOSPHORUS COMPOUNDS (Continued)

Common Name	Other Name	R^1, R^2	R^3	Properties	Oral toxicity: minimum period application—harvest
PHOSPHOROTHIOLOTHIONATES					
	Methyl-trithion	methyl	*p*-chlorophenylthiomethyl	Contact insecticide and acaricide.	Moderate, 2a
morphothion [1]		methyl	morpholinocarbonylmethyl	Contact insecticide and acaricide. Some systemic action.	Moderate, 2a 3 weeks
phenkapton [1,3]		ethyl	2,5-dichlorophenylthiomethyl	Contact acaricide, with residual action.	Moderate, 2a 4 weeks
phorate [1, 3]	Thimet	ethyl	2-ethylthiomethyl	Systemic insecticide and acaricide. Used for seed treatment.	High, 1a
phosazin-methyl [2]	Gusathion Guthion	methyl	3,4-dihydro-4-oxobenzo-1,2,3-triazin-3yl-methyl	Contact insecticide and acaricide.	High 1a, Regulations, Part II 3 weeks
	Phostex	mixture of bis (dialkyloxy-phosphinothioyl) disulphides		Insecticide and acaricide.	Low, 3b
thiometon [1,3]	Ekatin	methyl	2-ethylthioethyl	Systemic insecticide and acaricide. Moderate persistence.	Moderate, 2a
	Trithion	ethyl	*p*-chlorophenylthiomethyl	Contact insecticide and acaricide, with residual action.	High, 1a

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[1] BSI common name
[2] BSI proposed name circulated for comment
[3] ISO proposed name circulated for comment

former, of high mammalian toxicity (1a), is being used experimentally in bait form for controlling houseflies that have acquired resistance to chlorinated hydrocarbon and phosphorus insecticides; the latter, an experimental nematicide and soil disinfectant, is said to be relatively safe to warm-blooded animals. Another compound dazomet[2] (tetrahydro–3,5–dimethyl–2H–1,3,5–thiadiazine–2–thione; Mylone) is a soil fumigant with some nematicidal action and is of relatively low toxicity (3a) to mammals. Metham–sodium and dazomet act by liberating methyl *iso*thiocyanate as a toxic vapour in the soil and care is needed to prevent plant damage. A new contact acaricide of low mammalian toxicity (3a) has also been developed; its active ingredient, at present not fully disclosed, is designated as a " phenol-ester." This compound and fluoroacetamide represent new departures from the established types of spray chemical.

General Conclusions

The compounds named indicate the scope of developments over the past few years likely to be of interest to the entomologist. New insecticides are continually being produced, and advances are also being made in the fungicide and herbicide fields. The rapid pace at which innovations occur raises serious problems for those engaged in research, advisory and regulatory work. It is becoming increasingly difficult to carry out adequate tests on which to base sound recommendations for the growers; indeed, as soon as information is obtained on one chemical it is likely that the growers' interest will switch to another. We have, therefore, to rely more and more upon the manufacturers' assessments of the capabilities of their products. The inability to check, within a reasonable period, more than a few of the claims made, has repercussions on approval and registration schemes. In this country the official Crop Protection Products Approval Scheme, started eighteen years ago, has found increasing difficulty in keeping pace with developments and has recently been replaced by another scheme incorporating more extensive field trials and designed to give quicker results.

To what extent are the new developments helping us out of our difficulties? The most encouraging sign has been the high proportion of the new chemicals that show moderate or low mammalian toxicities. This is to be welcomed, especially in the organo-phosphorus group. Some of the older highly toxic chemicals, *e.g.*, parathion, are still used, but there is every expectation that they will become less important as the potentialities of the more recent materials become better known and as new compounds emerge.

The problem of the development of insecticide tolerance in insects, including those of agricultural importance, has been admirably discussed by Way (1959). Resistance is most likely to develop in pests of crops, often under conditions of monoculture, which are intensively treated with insecticides. In this country, resistance has been acquired only by the glasshouse and fruit tree red spider mites. In 1958, workers from East Malling found that the fruit tree mite in Essex had developed resistance to chlorbenside, but adequate commercial control was obtained in 1959 by single applications of phenkapton, dimethoate or tetradifon, indicating that sufficient acaricides of differing modes of action were available to enable growers to use a three or four-year rotation in chemical control (Collyer and Kirby, 1959). Such results, coupled with the rapid development of new products and the general awareness of the conditions inducing resistance, encourage the belief that, so far as agricultural pests are concerned, the problem of acquired resistance will be kept well in hand.

What of avoiding the destruction of beneficial insects? This may be achieved by selective toxicity inherent in the chemical and, to some extent, by modifying application procedures to aid selective action. More and more claims are being made of selective toxicity; the triazinyl phosphorus compounds, for example, are reputed, so far as tested, to have shown little toxicity to insects other than Aphids. The claims need confirmation, but offer promise that chemicals of greater specificity will be found. The systemic insecticides act selectively upon sucking insects once the hazards incurred by the general insect fauna during the initial application have passed; seed and root treatment should therefore be especially advantageous. The greatest risks arise from the use of persistent contact chemicals of high and general insecticidal action. The control of soil pests, which is rapidly extending, may raise special problems in relation to beneficial insects; soil treatment, year after year, with highly toxic persistent chemicals, may prove disadvantageous in the long run.

Hazards to bees are difficult to assess. Many of the organo-phosphorus insecticides are highly toxic to bees and should not be used on flowering plants. Some which have short residual actions may be used safely when bees are not foraging, and those that are rapidly taken up by plants also tend to be less hazardous. Schradan, which is highly toxic to other insects, is comparatively innocuous to the bee. Birds usually show less resistance to insecticides than mammals, and indignation has been aroused by the killing of game and other birds by some of the older phosphorus and chlorinated hydrocarbon insecticides. Information on the effects on birds of the newer insecticides is scanty, but there is reason to believe that improvements will be seen. Little is known at present of the effects of the newer compounds on fish, which readily succumb to the chlorinated hydrocarbon insecticides but in general are less easily affected by the phosphorus compounds.

More information is needed on the relative susceptibilities to particular insecticides of harmful and beneficial species. At present we tend to use amounts of insecticides in excess of those that are necessary, provided they are properly applied. Dosage is thought of in terms of a given amount of chemical to be applied per acre, rather than as the amount deposited or required upon the plant surface; if volume is reduced, the concentration is proportionately raised. The formulation of the chemical and the way it is applied should suit the crop to be treated; if this is ensured, it should be possible to obtain efficient pest control with lower dosages of active ingredients than are now used. In this way, operator and consumer risks would be reduced, and any differing susceptibilities of pests and predators might be exploited. Insecticides are available in plenty, but I would re-echo Professor Kearns' remark at the last Conference that we still need to learn how to use them to the best advantage.

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Discussion

Dr. M. L. Roonwal enquired whether diazinon would prove effective against *Cimex*, and whether there was any information on its toxic effect on human beings. Dr. Martin replied that he had purposely limited the content of his paper to agricultural usages. As diazinon is of moderate or low toxicity to mammals, its use against bed bugs would be possible, but the topic would probably come up for discussion when Dr. J. M. Barnes considered some of the toxicity hazards of modern insecticides in the afternoon.

Dr. J. M. Barnes stated that diazinon had been used extensively in several countries for the control of flies in domestic premises and that, as no accidents from its use had been reported, it was reasonable to assume that it would be safe for use against bed bugs. He had, however, no data on its effectiveness against that insect, and wondered whether it would be sufficiently persistent.

The Chairman asked whether Dr. Roonwal had experienced resistance to other materials by *Cimex*, in view of his interest in the use of diazinon, to which Dr. Roonwal replied that bed bugs were not well controlled by DDT, although difficulty of penetration rather than resistance seemed to be the problem. The Chairman advised discussion with Dr. Busvine. Mr. Q. A. Geering reported that some work on the subject had been done in East Africa, and that he would furnish Dr. Roonwal with a reference to that work.

Dr. F. J. Simmonds drew attention to the value of selective insecticides as an adjunct to biological control methods, and asked how far the subject of low toxicity to Hymenoptera had been investigated. He had both honey-bees and parasitic Hymenoptera in mind; some materials were shown in Dr. Martin's list as relatively non-toxic to bees, and he wondered whether they would be equally non-toxic to other beneficial Hymenoptera. Dr. Martin replied that such aspects had not yet been investigated to any extent. Some of the newer materials had shown promising specificity, but the claims made for such specificity required substantiation and there were few workers engaged on such investigations. Specific toxicity was usually found to embrace relatively broad groups of insects rather than narrower, specific groups, and moreover it would appear that the honey-bee differed in its response to insecticides from most other insects.

Mr. D. J. Colwill asked whether the manufacturers' methods of screening and testing potential pesticides could not be streamlined in some way, to reduce the cost of developmental research from the present high figure, which a few years ago was said to be in the region of a quarter of a million pounds for each compound ultimately placed on the market. In reply, Dr. Martin said that, from the manufacturer's viewpoint, a new compound had to be developed as quickly as possible if it was to achieve worthwhile sales. Full testing had to be carried out before the material was placed on the market, and it was this that was responsible for much of the high cost of development in the United Kingdom. Such tests were often limited to the compound itself and not to some of its later formulations, and the new Approval Scheme should ensure that products in the United Kingdom would receive sufficient testing before appearing on the market. Dr. Galley added that he was of the opinion that the cost of developing new pesticides would always be extremely high because of the need to convince governmental bodies of the efficiency and low hazards of the new material.

Dr. P. Becker, in asking whether Dr. Martin could give the meeting some idea of the rules governing the choice of common names for pesticides used by the Nomenclature Committee, suggested that many of them could be somewhat less complicated, and that the names used in the first place by the manufacturers were often simple and easy to remember. Dr. Martin agreed that the proprietary name of a new material was often suitable, but difficulty was sometimes experienced in persuading the manufacturer to release it for common use. The Nomenclature Committee was governed in its selection of a name by the three criteria of shortness, pronunciation [not more than three syllables], and some relationship or clue to the chemical structure of the compound—at least for the initiated. He illustrated this by reference to the herbicides, 2–*sec.*–butyl–4:6–dinitrophenol, which was known as dinoseb, and 2–*sec.*–amyl–4:6–dinitrophenol, known as dinosam: there was not yet one known as dinosaur! As time went on, some confusion between the multiplicity of compounds and common names would become almost inevitable.

Dr. W. A. L. David asked whether Dr. Martin knew of any work being carried out in the United Kingdom on carbamates as insecticides. Only two appeared in the speaker's prepared list, but many carbamates had been synthesised and found active in the U.S.A., and he thought it desirable that some attention should be devoted to them in the Commonwealth. Dr. Martin agreed that the carbamates were an interesting group, but had no knowledge of further work on them in this country, and another speaker stated that WHO was using carbamates experimentally as a fly poison, on the hypothesis that their long persistence might assist in overcoming resistance. Mr. K. B. Armstrong said that, although Sevin had given encouraging results against cacao Mirids in the laboratory, its field use in Ghana had been rather disappointing, as formulations lacked adhesion and were liable to be washed off in the rains. Dr. G. H. L. Dicker referred to tests in progress at East Malling with Sevin against *Cydia pomonella* (L.). It had the virtues of low mammalian toxicity and persistence, and was as good as any known material against *C. pomonella*, but it had a wide spectrum of activity and destruction of beneficial insects was its greatest drawback; consequently it offered little advantage over DDT. Similar action was reported by Mr. E. O. Pearson on pests of cotton, especially *Diparopsis castanea* Hmps. in Southern Rhodesia and Nyasaland, but it was too early to comment on its possible side-effects.

Dr. W. A. L. David wished that manufacturers would say more about experimental materials, for he believed that in California some fifty carbamates had been examined and shown to be effective as contact and systemic insecticides. Mr. Q. A. Geering replied that, of the many carbamates tested, only Sevin and Isolan were of proved value, although doubtless work with others was still proceeding.

Mr. G. A. Emery provided the information that, in addition to its use against codlin moth, Sevin was showing itself useful in the United Kingdom on poultry against red and northern fowl mites, and against cockroaches. It was of particular value against dieldrin-resistant strains of the latter. He thought that its persistence would militate against its use where the preservation of beneficial insects had to be considered; contact insecticides applied against biting insects must, inevitably, also destroy the beneficial species. A phosphorus carbamate [Mecarbam] was being placed on the market which was semi-systemic in action, and had been shown to be effective against Aphids and Tetranychids.

Mr. I. R. Harrison disagreed with some of the previous speakers, in their suggestions that Sevin was comparable with DDT, for although it had shown strong activity against the poultry red mite [*Dermanyssus gallinae* (Deg.)], it had also proved of little value against sheep blowflies [*Lucilia* spp.]. Sevin was probably better than most other carbamates, for Union Carbide had examined many hundreds of compounds before selecting Sevin for development. Mr. J. C. Felton agreed with the last speaker's remarks on the occurrence of some degree of selectivity with Sevin. It was probable that Sevin is active against some pests—notably Lepidoptera—which are less well controlled by other materials.

Professor H. G. H. Kearns stated emphatically that applied entomologists were appalled by the present number of insecticides and acaricides available to them. There was a general tendency to rely too much upon them: it should not be forgotten that good biology was the spearhead of the attack, and that the application of insecticides indiscriminately should not be the method of choice.

Mr. F. Wilson, referring to Dr. Martin's mention of the effects of applications of insecticides to mixed populations containing beneficial insects, asked to what extent manufacturers' tests were standardised and whether they could not include appropriate natural enemies in the range of organisms used in screening tests. Particular attention seemed to have been paid to the effects of new materials on honey-bees, probably because they were looked after by those interested in the honey industry, but there were no similar organisations to consider the welfare of other beneficial insects. To this, Dr. Martin replied that testing by the insecticide industry followed a laid-down pattern in only two respects: the first was in relation to residue data, and the second to toxicological data, because of the potential hazards of an unknown compound. There were, he believed, no standardised methods of field testing, and each company tended to use its own techniques often in great variety. He did not see, indeed, how such testing could be standardised. Mr. Wilson thought that as most manufacturers used a definite range of test organisms in their preliminary laboratory work, some beneficial insects could well be included, and Dr. Martin agreed that information on the differential pest-predator toxicity of a new compound could be invaluable, but he did not think that any manufacturer at present pursued any work along such lines.

Mr. W. Heeley said that there was exchange of information on techniques between manufacturers, however much they might be rivals in other aspects of their work, and this resulted in at least some uniformity of testing procedures. With regard to the testing of new compounds against beneficial insects, he considered that small-scale experiments would be unlikely to provide reliable results, that experience from use with the product was the only way to obtain such information, and that such experience was only obtained by the applied entomologist in the field under natural ecological conditions. Mr. Q. A. Geering also thought that screening could usefully be carried out with the honey-bee as one of the test insects, for a good insecticide was generally a good killer of bees. He considered that, although predictive selectivity of action between groups of insects was not yet possible, considerable advances had been made in recent years in discovering compounds that were highly toxic to insects but not to mammals, and this was an important aspect of selective action.

Mr. C. R. Ribbands said that insecticidal materials were of two kinds as far as their effects were concerned on bees: those that acted rapidly and were lethal only to the foraging bee, and those that were more persistent [of which he instanced lead arsenate] and could be carried back to the hive and there cause irreparable damage. This linkage of lethal effect with behaviour served to underline the difference that exists between honey-bees and parasitic Hymenoptera, and which prevents them from being considered together.

The discussion closed with a final reference by Dr. Martin to Dr. Hubert Martin's work on the mechanisms of differential toxicity, in which attempts had been made to establish enzyme differences between insects and mammals. It had been found that, although cholinesterase was common to both, carboxyesterase occurred only in insects, and from that might well spring the beginning of fundamental work relating chemical structure with activity.

DISCUSSION ON PROBLEMS IN THE USE OF INSECTICIDES

Chairman: Professor H. G. H. Kearns, o.b.e.
Director, Agricultural and Horticultural Research Station, Long Ashton

By way of introduction, the Chairman said that the mention of Dr. Hadaway always brought mud huts to mind, but that the connection with the subject before the meeting was not so intangible when one considered that in the tropics many millions of people lived in mud huts, and shared their accommodation with malaria-carrying mosquitos. Dr. Hadaway's experience with residual sprays in the control of mosquitos could find applications in very different uses of insecticides.

Problems in the Use of Insecticides

By Dr. A. B. Hadaway
Colonial Pesticides Research Unit, Porton

Earlier this morning, Dr. Martin described the new insecticides now available. Some of the problems associated with their use are also new, but many are old ones. The first problem is to decide whether the use of an insecticide will be beneficial and economic under prevailing local conditions. It was pointed out at the 1954 Conference that insect pest control does not necessarily increase crop yields, and the application of spray materials was of little or no importance on native holdings until the cultural conditions had reached a standard that ensured reasonable yields. It is of interest to note that since then, for example in trials carried out by the Colonial Pesticides Research Unit, Arusha, in Zanzibar and Tanga, there was no appreciable sustained increase in the yield of coconuts when *Pseudotheraptus* damage was kept at a low level by means of insecticides (McKinlay, 1959). On the other hand, there were indications that yields could be increased by clean cultivation of the ground beneath the palms. In Uganda, Ingram (1960) found that DDT applications to sorghum gave varying degrees of control of stalk borer but no significant increases in yield.

These results, however, apply only to the particular local conditions, and there is no doubt that throughout the world insecticides do play a vital and invaluable role in the protection of growing crops and of harvests during transit and storage, and in the prevention of transmission of vector-borne diseases. Unfortunately it is not sufficient merely to find a chemical with insecticidal properties and distribute it at so many gallons or pounds per unit area. For efficient and economic use, it must be put in the right place, at the right time, and in a form available to the insects. At the same time, it is essential to avoid or reduce to a minimum undesirable side effects such as disastrous upsets in the natural mechanisms of pest control, injury to the crop, or toxic residues.

Achievement of these various aims depends upon the close co-operation of scientists of several disciplines. Entomological information, however, is the first requirement, for control methods must be based on adequate knowledge of the insect pests. Studies of the life history and ecology of the insect are necessary to show at which stage of the life cycle or at what season the pest is most accessible or susceptible to attack, and thus to determine the timing and important sites of application. For example, the tsetse fly *Glossina palpalis* (R–D.), frequently rests on vegetation at the edge of water, and the application of insecticides only to the vegetation at the edge of rivers and lakes can reduce populations of this species to low levels (Wilson, 1954; Woodcock, 1957). Recent ecological studies have shown that other more widely dispersed species of tsetse also have preferred resting sites, and in Uganda, treatment of the trunks and branches of one species of tree (*Acacia gerrardii*), of which there are only about five per acre, very nearly eradicated *G. morsitans* Westw. from about fifteen square miles of savannah woodland (Hocking, 1958). In West Africa, it has been found that *G. morsitans* can survive at the end of the dry season in only very small foci and that treatment of these foci with insecticides may give effective fly control (MacLennan and Kirby, 1958).

Furthermore, knowledge of some behaviouristic or ecological characteristic may allow a certain measure of selectivity to be achieved. Examples that come to mind are the use of attractants and baits for Mediterranean fruit flies and houseflies, and the use of seed dressings to control some soil insects.

The next problems for consideration are concerned with getting the insecticide to the important sites. In recent years the use of insecticides as dry dusts has decreased largely because of the disadvantages of poor adhesion to and retention on surfaces. Dry materials are being used, however, in special circumstances, in the form of granules and pellets. These offer the advantages that their distribution is influenced less by wind and they can be placed fairly accurately on specific targets. They have found uses in the application of some soil insecticides and mosquito larvicides where a dense vegetation cover would prevent liquid droplets reaching the soil or water below; and in the application of insecticides to reach, for example, corn borers in leaf whorls and frog hoppers at soil level in sugar cane.

Generally, however, insecticides are applied as liquid sprays—of solutions, oil-in-water emulsions or aqueous suspensions—and the fate of the liquid droplets is determined largely by the degree of dispersion.

When a droplet is released into still air it accelerates to a constant settling velocity, its terminal velocity, which decreases with drop size, for example, from 210 cm./sec. for 500 micron water drops to 0·3 cm./sec. for 10 micron drops. In most cases the air is moving with the droplet. When a droplet is carried in an airstream towards an obstacle it may have sufficient inertia to resist the change in direction of the divergent air flow and will impact on the obstacle, otherwise it will follow the air flow around the obstacle. Broadly speaking, the smaller the droplet, the slower the air speed, and the larger the obstacle the less efficient is the impaction. For example, droplets less than about 30 microns in diameter fail to impact on a 1 inch diameter cylinder in air moving at 2 m.p.h., and the collection efficiency of 100 micron drops is only about 50 per cent.

As a generalisation, sedimentation tends to be more important with larger drops (greater than 100 microns) and low air speeds, and results in deposition on upper surfaces only, and localised shielding such as that of one leaf from another may be pronounced. Small drops, less than 50 microns, tend to by-pass large obstacles especially in slow moving airstreams and are better able to reach sites inaccessible to large drops, but their movement is affected by turbulence of the air. In considering the optimum drop size for penetration and impaction, it must be remembered that much of the volume may consist of water or volatile solvents, which will result in a rapid decrease in size of the droplet during flight, especially under high temperatures, and this will again reduce the chances of impaction.

To achieve immediate contact on flying insects in confined spaces such as buildings or aircraft an aerosol of very small particles (of the order of 10 microns) with low terminal velocities is required so that the droplets remain airborne as long as possible. In contrast, a coarse spray of relatively large drops is required to put deposits on the interior surface of buildings for residual contact action, and small airborne particles should be reduced to a minimum.

Outdoor application problems are much more complicated due to the great variations in size, shape and composition of the spray targets, and also the wide variations in meteorological conditions. All these factors influence droplet distribution most profoundly. For immediate contact on insects, such as tsetse flies, in dense woodland, drops in the range of 5 to 50 microns are required but effective use of such small drops is limited to periods when the atmosphere is relatively stable and wind speeds are low. Rather larger drops in the 50–100 micron range can be used effectively when there is no vegetation cover, for instance against adult locusts. No doubt Yeo's work (Yeo, 1954; Yeo and Thompson, 1954; Yeo, Akesson and Coutts, 1959) on the deposition of insecticide sprays from aircraft will be referred to in some detail in later sessions on tsetse and locust control.

When deposition of spray on crops is desired, the problems vary considerably with the method of spraying employed. High-volume or run-off spraying involves the application of large quantities of dilute sprays, from 60 to 200 or more gallons per acre, as large droplets which readily impact on crop surfaces but which have little penetration. The number of drops is so large that when they impact they coalesce and saturate the surface, and if this does not wet easily the spray tends to run off. Low-volume spraying, on the other hand, utilises volumes of less than 20 gallons of concentrated spray per acre, dispersed as fine drops which are assisted to the target by air blasts. In a recent review of application problems Courshee (1960) quotes the results of his experiments on deciduous trees before they came into leaf. Seventy per cent. of the fine spray from a mist blower drifted out of the half-acre plots, and the same proportion of a coarse spray was found on the ground underneath the trees. Two methods of spraying gave similar results—both were very wasteful.

Selection of the most effective spraying method is not easy. The general principles governing the distribution and deposition of spray droplets can be determined from theoretical considerations and laboratory studies, and the performance of a spraying machine in terms of the average drop size and dosage applied can be measured. It is much more difficult, however, to relate this physical data to biological effectiveness. There is, indeed, a need for much more comparative field data on which to base the choice of spraying equipment most suitable for the control of a specific pest.

The biological effectiveness of the insecticide reaching the target is influenced by a number of factors. Obviously the behaviour and habits of the insect are of importance in determining the extent to which it comes into contact with the insecticide. Many insects are immobile in their feeding stage and are frequently protected within buds or folds of plant surfaces, and unless the insecticide has a systemic action the extent and uniformity of the coverage can be very critical—certainly much more so than when the insects are highly mobile, as are, for example, *Antestia* on coffee and Jassids on cotton. Again, the intermittent contacts of some flying insects, such as mosquitos and tsetse flies, are obviously different from the contact made by a caterpillar or beetle crawling on a deposit for a considerable time. It is of interest to note that Miss Gratwick (1957) investigated the uptake of particles from dust deposits by five different species and found that smaller insects picked up more particles per unit body weight at each step, and that differences in the collecting efficiency of tarsal segments were due either to structural differences or to differences in the part played by the segment in walking.

The availability of the toxicant to the insect is also affected by the physico-chemical properties of the insecticide formulation and by those of the material to which it is applied. I can illustrate this by reference to the work of my colleague Barlow and myself on the effectiveness against mosquitos of deposits on various building materials. Adult mosquitos alight on these surfaces when they enter houses for a blood meal, and the resting time may vary from hours to minutes depending on the habits of the species and the irritant properties of the insecticide. DDT, for instance, may activate mosquitos and stimulate them to fly from a deposit after only a few minutes contact, and availability of the insecticide is then very critical. Many building materials—bricks, plaster, and dried mud used commonly in house construction in the tropics—are porous, and when they are sprayed with solutions or emulsions the liquid is rapidly absorbed and only a low percentage (usually much less than 5 per cent.) of the dosage of insecticide applied remains at the surface where it is required for contact action. Mosquitos must rest on the treated surface for many hours before they acquire a lethal dose, and these formulations are therefore wasteful and inefficient. On the other hand, when an aqueous suspension of a wettable powder is applied to these porous materials the wetting agent solution is absorbed but the solid particles of insecticide and inert carrier are filtered off at the surface where more than 90 per cent. of the active ingredient can be recovered. These surface deposits are readily available for pick-up on the tarsi of mosquitos, and a lethal dose may be acquired after only a few minutes contact. The smaller the particle of insecticide the more easily is it picked up and retained by mosquitos and we were able to show an inverse relationship between particle size of DDT and other chlorinated hydrocarbons and toxicity (Hadaway and Barlow, 1951). For practical purposes the optimum particle size is of the order of 10–20 microns, because very small particles may penetrate the pores of the substrate and not be available to the insects.

The properties of the formulation and the material to which it is applied also affect the persistence and residual toxicity of an insecticide. For example, we found that deposits of

DDT and dieldrin wettable powders had a much longer residual contact toxicity to mosquitos on plywood coated with a cellulose paint than on plywood coated with an oil paint. The insecticide slowly dissolved in the latter and was removed from the surface. Perhaps one of the most interesting examples of removal of insecticide from a surface is that of solid particles of chlorinated hydrocarbons by many of the dried muds, particularly those made from red lateritic soils, used in house construction in the tropics (Barlow and Hadaway, 1955, 1958; Hadaway and Barlow, 1952). The insecticide particles are rapidly sorbed, often in a day or two, into the sub-surface layers of the dried mud, with the result that biological effectiveness is considerably reduced. However, the process is beneficial in that the persistence of a volatile insecticide such as gamma–BHC is increased and biological activity is maintained, at a reduced level, for a much longer period than it is on a non-sorptive surface.

The persistence of a volatile insecticide may also be increased by the incorporation in formulations of various materials such as resins to reduce the vapour pressure of the insecticide. Formulations based on resins, particularly urea-formaldehyde resins, are also used as insecticidal coatings to increase the persistence of volatile insecticides or as a means of bringing a crystalline bloom of insecticide to the surface from within the film.

Recent attempts to substitute organo-phosphorus compounds for chlorinated hydrocarbon insecticides in formulations for application to building materials have produced problems. Many organo-phosphorus compounds are liquids and when wettable powder formulations are dispersed in water a high proportion of the active ingredient may be displaced from the inert carrier and dispersed in the water phase. Application to porous building materials then results in loss of surface deposits by absorption. In addition the organo-phosphorus compounds may be hydrolysed and decomposed in dried mud and their biological activity is rapidly lost.

Similar considerations must be given to interaction between formulation and plant surfaces if the desired effect is to be obtained. This may be retention on leaf surfaces for residual contact action, or it may be a very different one of penetration through the leaf cuticle and translocation within the plant for systemic action. Knowledge of the structure and chemistry of plant cuticles is therefore fundamental to the efficient formulation of crop-protection insecticides. Advances in this field have been made by the use of new techniques, for example, in electron microscopy to study leaf surface structure (Juniper, 1959). At Long Ashton, Dr. Martin and his team have shown that the leaf cuticle consists of a spongy layer of cutin impregnated with waxy material covering the epidermal cells and they have developed methods for the quantitative determination of cutin and waxes.

Factors influencing the accumulation and adhesion of insecticides on leaf surface were reviewed recently by David (1959). One, the wettability of leaf surfaces, varies from plant to plant and is of importance in determining amounts of spray that are retained or are lost by bounce and run-off. Effects of incorporating surface active agents in sprays have been considered by Furmidge (1959). Adhesion of insecticides to plant surfaces is another factor of importance, for it determines on the one hand, ability to withstand the weathering action of rain, dew and wind, and on the other, availability to insects. From the latter point of view the work of Lewis and Hughes (1957) is of interest. They showed that lipophilic particles have an affinity for both the lipoid epicuticle of insects and leaf waxes, and that lipoid-soluble particles adhere more easily to blowfly epicuticle and to a leaf wax than do lipophobic particles.

In this brief survey I have tried to emphasise the need for entomological data on which to base control methods, for dispersion of the insecticide so that as much as possible of the dosage applied reaches the important sites, and for formulation of the insecticide so that it can best perform the task required of it. I am well aware that there are other problems associated with the use of insecticides, but I hope that sufficient has been said to stimulate other speakers to contribute to the discussion at this and later sessions when specific problems are reviewed.

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Discussion

Mr. E. A. Parkin, referring to Dr. Hadaway's mention of the strong sorption of insecticides in the surfaces of buildings, asked whether any work had been done on the use of special solid carriers which would compete with the surface in sorption coefficient and thus keep the insecticide at the surface. Dr. Hadaway replied that sorption could be reduced by the use of some materials that formed a layer between the insecticide and the surface, but that improved formulations gave better results. Wettable-powder formulations had been produced that retained dieldrin at the surface after spraying, but in field use the results obtained proved no better than those given by standard techniques. Volatile insecticides, of which he instanced dieldrin and γ–BHC, were beneficially sorbed, for the material was then slowly released and was not subject to weathering. Deposits could be increased by the use of stickers, but a criticism of such formulations was that they sometimes were so effective that little insecticide was passed on to the insect.

The Chairman enquired whether coumarin resins had been found to prolong the toxicity of residual insecticides to a worthwhile degree, in addition to making them more readily soluble, to which Dr. Hadaway replied that they reduced the vapour pressure of insecticides and therefore prolonged their useful life; an example was a recent BHC-Cereclor formulation that showed considerable promise in Africa for the control of mosquitos in houses.

In answer to a question by Dr. M. L. Roonwal, on whether materials persisted longer if they were mixed with mud instead of being sprayed on it, Dr. Hadaway stated that the material would be more evenly distributed and that sorption would be more rapid.

Mr. F. A. Squire drew attention to the problem of application to crops in the tropics, where insect activity coincides with the rains, and so called for a formulation possessed of quick-drying and rain-shedding properties. Dr. Hadaway thought that this was a job for the chemists; the Chairman, adding that flush growth of the host plant also followed the rains, with the result that much of the rapidly developing plant material was not covered by the original application in any case, considered the problem as almost insoluble.

Dr. J. T. Martin said that the use of stickers with fungicides in general gave a decreased original deposit, and that deposits had been found to decrease at about the same rate whether or not a sticker was incorporated.

Mr. J. K. Eaton, referring to the importance of formulations which laid down the highest possible deposits on plant surfaces as the first stage in achieving persistence of those deposits, asked whether, in wettable-powder formulations, the cohesion between the particles as they reached the surface was specific to the toxicant used or whether it was influenced by the nature of the spray adjuvants. To this, Dr. Hadaway replied that he thought changes could be brought about by formulation, but more information was required on the forces involved in surface interactions, so that the operator could arrive at an optimum set of conditions between the material and the target surfaces. As an example of the employment of this line of approach, he cited Kearns' work in the West Indies with Bordeaux mixture (0·2 per cent. copper), which gave a deposit of 6–7 μg. of copper per sq. m. when suitably modified with wetting agents, as compared with only 1 μg. when used without a wetter.

There was a need for crop lists to be prepared, categorising them according to their wettability, with specific recommendations of the formulations suitable for use on each group. **Mr. Groves** thought that it was therefore obvious that formulations should be devised for use on the most intractable surfaces, and that they could then be used on surfaces with better properties as well, but **Dr. J. T. Martin** did not agree. He considered that it would lead to wastage, and that ideally one should formulate for the crop under consideration. The **Chairman** said that **Dr. Martin** and he had experience of banana, one of the most difficult crops to treat, and of coffee, one of the easier; a spray that was formulated to give good deposits of cuprous oxide on the banana leaf left almost none on coffee. It was therefore suggested that formulation for specific crops would ultimately be necessary to ensure the optimum results. **Mr. E. O. Pearson** asked if anyone present could say whether manufacturers themselves tested their formulations on a range of types of tropical crops, with due regard for the widely differing rainfall and temperature conditions under which these were grown. **Dr. D. Cochrane** thought that some manufacturers did maintain testing stations in tropical regions, although there were difficulties in that all tropical crops would not grow in any one area. Most manufacturers, however, tested their products widely before they were placed on the market, and often the tests were carried out by a large number of separate organisations in different territories, so that the performance of a material could be assessed under different conditions of climate, soil, and so on. In reply to a query by the **Chairman**, he said that, within reason, formulations were made for particular crops, and **Mr. Q. A. Geering** elaborated this. Starting off with a single formulation, it was tested under a variety of conditions, and few real difficulties arose in doing that. Manufacturers of course wanted the results as soon as possible, and there was a tendency for government entomologists to approach the tests more cautiously and to ask for further time with a particular trial.

At this juncture, **Mr. E. O. Pearson** remarked that everyone knew that there was good co-operation overseas between the manufacturers and the entomologists who tested the materials, but he still wondered if, in fact, the reports submitted to the manufacturers were sufficiently detailed with regard to such aspects as crop surfaces and local rainfall to provide them with suitable information on which to base changes in formulation.

Mr. D. J. Colwill thought that formulation was still in its infancy, although manufacturers appeared to have taken care of the more obvious aspects. The initial deposit was, however, affected by field peculiarities and he wondered whether the use of surface-active agents alone was desirable. Low-volume, oil-based sprays, for example, seemed to persist longer than formulations containing wetting agents in areas of high rainfall.

Mr. R. F. W. Holliday reverted to the subject of the availability of insecticides from mud surfaces to enquire why, whereas BHC was released slowly after adsorption, the same thing did not happen with phosphorus compounds, even although they possessed high vapour pressures. **Dr. Hadaway** replied that a similar process might well also occur in phosphorus compounds, but the picture was more complicated because organophosphorus materials, unlike the chlorinated hydrocarbons, decomposed in the mud and were thus not persistent.

In drawing the discussion to a close, the **Chairman** stressed that Dr. Hadaway had really told the meeting that it must get to know its target better; understand the problem, its objectives, and the reaction of the surfaces to the material being applied. The usual approach is rather casual, implying that everyone understands the target surface, but exact work is essential and will become more so, with consequent extention of existing micro-assay techniques, for it is deposits at their lower levels that are of greater interest than massive applications.

DISCUSSION ON HAZARDS AND PRECAUTIONS ASSOCIATED WITH THE USE OF PESTICIDES

Chairman: Dr. I. Thomas, *Infestation Control Division, Ministry of Agriculture*

The **Chairman** said that the papers about to be read were concerned with two separate aspects of the subject. Dr. Barnes, the first speaker, was the man who was generally consulted on questions of toxicology, whereas Dr. Miller, the second speaker, was involved in the assessment of insecticides from the standpoint of safety, and would be dealing with the regularity aspects of their use.

Hazards from Using Pesticides

By Dr. J. M. Barnes
Toxicology Research Unit, Medical Research Council Laboratories, Carshalton

While the use of pesticides continues to increase there seems to be no parallel rise in the incidence of poisoning among the users. Most of the really serious accidents with pesticides have not arisen during their use in the field. Some examples of such incidents will be given later.

In my opinion this record for the use of these toxic materials is the result both of increased general experience and a trend towards the use of less toxic materials, particularly among the organophosphorus compounds. Although the opposite trend is seen in the chlorinated hydrocarbon group, safe use under field conditions is largely a matter of common sense. Common sense is normally the product of experience and intelligence. It cannot therefore be expected among people whose first contact with any chemical in bulk happens to be with a toxic pesticide.

It is impossible to overstress the need for the education and training of those who are to handle these materials. With training comes good discipline and a proper organisation of the operations. Without this all the protective devices in the world would prove ineffective in preventing accidents. Training and discipline should be necessary in order to ensure that the pesticide is applied properly to the crop. Those responsible for the ordering of the use of pesticides on crops must make sure that their instructions always include attention to details of how to handle the pesticide from the time the concentrates are removed from store until the final clearing up of the equipment at the conclusion of the operation. This includes the safe disposal of empty or half-empty containers.

Under most conditions elaborate protective equipment to shield the operator from contact with the pesticide is impracticable and experience shows it to be unnecessary.

Studies on men applying pesticides under different conditions show that the major route of exposure is by way of the skin and not by the inhalation of droplets or dusts. Volatile materials in closed atmospheres obviously present special problems but even when spraying the interiors of houses with wettable powder suspensions much more of the insecticide is deposited on the bare skin than is inhaled. As most pesticides can penetrate the skin it is clearly necessary either to protect the skin or remove contamination by washing. For most of the dilute preparations plain cotton forms an adequate protection. In many types of operations it is the skin of the neck, shoulders and arms that need protection and a broad-brimmed hat of a light material is useful additional protection. For exposed skin regular washing with soap and water is adequate and must be enforced by good discipline and the provision of facilities to make washing possible. A minority of pesticides, for example organo mercurials and some herbicides, are directly irritating to the skin but many of the others will penetrate the skin without producing an irritation or other visible change.

Special care, however, must always be taken with pesticide concentrates and rubber gloves should be worn to protect the hands when dispensing these. Fine dry powders are difficult to control, particularly out of doors, and they can readily adhere to damp skin. If inhaled they will be held up in the nose and eventually swallowed. There seems good reason for avoiding all dry powder preparations of the more toxic chemicals.

Before any toxic pesticide is introduced into a community steps should be taken to provide lines of communications for the rapid removal of any casualties to hospital. It will be helpful to notify medical officers that these materials are being used so that any specific therapeutic drugs may be obtained. Where teams are regularly exposed to pesticides some medical surveillance is desirable. For organophosphorus compounds field kits for examining blood cholinesterase levels are available and should be used. Blood tests for exposure to DNOC are simple to carry out in a modestly equipped hospital laboratory. For many pesticides, including well known materials like dieldrin which has caused many casualties in public health work, there are no simple procedures for establishing evidence of mild exposure. However, early symptoms of poisoning are often mundane—headache, dizziness, fatigue—and judgment will be needed before the possibility of poisoning is accepted or rejected.

Experience has shown that all pesticides generally available can be used safely without elaborate mechanical protective devices. What is absolutely essential is training and discipline with the provision of simple measures for personal hygiene.

The pesticides that have caused most trouble and been responsible for deaths or serious illness among operators in various parts of the world include:

Parathion (" Folidol ")	Many
Demeton	1–2
TEPP	About 10
DNOC	20–30
Pentachlorophenol	20–30
Dieldrin	Many (few, if any, deaths)
Endrin	1–2

On the other hand many more deaths or serious accidents have been caused by pesticides not being used for their proper purpose.

(1) Drinking from bottles and buckets that have held concentrates, such as TEPP, parathion, dieldrin. Therefore provide drinking water and vessels for thirsty operators.

(2) Contamination of food in store or transit from leaking drum of pesticides. Parathion and endrin.

(3) Eating dressed grain and beans (presumably stolen).

(4) Added to food in the kitchen or taken in error for medicine from unlabelled containers which have presumably found their way into the house for controlling pests, *e.g.*, DDT, chlordane.

(5) Attempts at personal disinfestation. TEPP, parathion, BHC.

(6) Curiosity. Playing with " empty " containers; chewing tablets—mainly children.

(7) Suicide and homicide.

Each of these examples provides an object lesson in the need to take as much care as possible of supplies of pesticides destined for legitimate uses.

The Safe Use of Pesticides in the United Kingdom

By Dr. E. J. Miller
Plant Pathology Laboratory, Harpenden, Herts.

In the time available I would like to describe briefly the practice in the United Kingdom with regard to the safe use of pesticides in agriculture.

The toxic hazards arising from the use of pesticides may be grouped, arbitrarily, into those affecting operators or users of the chemicals, those affecting consumers of treated crops, and those affecting livestock, domestic animals, wild life and others. The protection of all or any one of these groups may be achieved by voluntary or by legally enforceable means. From the brief description which follows you will see that in the United Kingdom at present we employ both, with a bias towards voluntary measures.

We have no legal requirement for manufacturers to register their products either for their safe use or their efficient use. Instead we have two voluntary schemes, both of which were freely agreed between industry and the Government before being introduced. Here we are concerned only with the scheme for the safe use of pesticides, that is, the Notification Scheme. The purpose of this Scheme is to ensure that all pesticides on sale in this country, if used in the manner described on the label, will be safe.

To observe the Scheme, a distributor, manufacturer or importer, who is about to introduce a new chemical, or new use or formulation of an existing chemical, must consider whether his product will offer a risk in use. If he is thoroughly satisfied it will not, he may exercise his discretion and not notify. If he has the slightest doubt, he should notify.

Thereafter, the onus is upon him to provide all the information required to satisfy Government Departments that the chemical will be safe when used in the way described.

The notification is received, on behalf of Departments, by the Ministry of Agriculture, Fisheries and Food, which also issues the finally agreed official recommendations. In most cases the notification is considered by a committee and its sub-committee, and by Departments before an answer is given. In a few instances the procedure may be short-circuited by omitting the committee stages.

In this country we have a permanent governmental committee charged with advising Departments on all risks arising from the use of pesticides. It is known as the Advisory Committee on Poisonous Substances used in Agriculture and Food Storage. It has an independent chairman, and its members consist of representatives, both administrative and technical, of interested Departments, together with five independent members from outside Government circles. There are no trade representatives on the committee. The committee has a Scientific Sub-committee which is composed entirely of scientists chosen for their expert knowledge of some aspect of pesticides. Membership includes chemists, biochemists, an entomologist and a plant pathologist, toxicologists, a pharmacologist, medicos and a veterinary parasitologist, as well as members with a special interest in wild life, or in pesticides used in food storage. As with the Advisory Committee, there are no trade representatives on the Sub-committee. This membership allows the Committee and Sub-committee to take into consideration the various, possibly conflicting, aspects likely to arise from the use of a pesticide and to reach agreement, or where necessary, an acceptable compromise.

When a notification is discussed by the Sub-committee, the notifiers are given the opportunity to attend the meeting, to give a statement and to answer questions. After they have left, the Sub-committee decides on the recommendations it will make to the Advisory Committee. These recommendations are solely scientific in approach. The Advisory Committee in considering them has to take into account other factors, which may make it necessary to modify the recommendations before sending them to Departments for endorsement. Finally the recommendations are sent to the notifiers for acceptance before publication. They are published as a loose-leaf dossier entitled " Chemical Compounds Used in Agriculture and Food Storage in Great Britain—User and Consumer Safety—Advice of Government Departments." The dossier, which is freely available*, is supplied to the official Agricultural Advisory Services, to industry, to local authorities and medical officers of health, to public analysts, to the trade journals and so on. Although intended for home consumption only, copies go to places all over the world.

The wide dissemination of the official recommendations ensures that the user of the pesticide receives the same advice by whatever means it reaches him—in a trade journal, from an official agricultural adviser or a trade representative, or on the label of the product—for firms closely co-operate with the Government in this respect.

The advice is usually given separately for each of the three groups mentioned earlier, namely operator, consumer and others. On operator hazards it may advise that the chemical is so toxic that its use should be banned or at least prescribed under law; or that it is not sufficiently dangerous to justify regulating, but voluntary precautions are necessary; or it is relatively non-toxic and requires no special precautions in its use. We have two laws in this country on pesticide use. One, the Agriculture (Poisonous Substances) Act, concerns agricultural workers, whilst the other deals with the use of HCN as a fumigant on stored products.

The advice on consumer safety aims at ensuring that the treated crop at harvest contains no harmful residues. Use may be restricted to certain edible crops, and advice is given on the maximum rate and number of applications, and a minimum interval before harvesting. According to the hazard offered by the chemical, so the number of restrictions will vary. Whilst the general provisions of the Food and Drugs Acts and certain regulations made thereunder give a broad protection to the consumer, there is at present no specific protection in the sense of legal tolerances—with one exception, arsenic.

The third part of the advice, on safety to others, includes advice such as: keep animals and poultry away from sprayed areas for a stated interval of time; for the protection of bees, don't spray orchards when in flower; to protect fish don't contaminate ponds and water courses with pesticide concentrate or washings; keep in tightly closed containers away from children, food and feeding-stuffs; and dispose of used containers safely.

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* Obtainable from the Ministry of Agriculture, Fisheries and Food, 5/8 St. Andrew's Place, Regent's Park, London, N.W.1.

This, briefly, is the current practice in the United Kingdom. It is based on close co-operation, partly voluntary, partly statutory, between the user through the manufacturer and the Government. We are trying to achieve our aim—and I believe we are succeeding—by giving the user a simple code of practice which if followed will ensure that the use of pesticides is safe. It does not mean that we shall never have tolerances, legal or voluntary, never have compulsory label registration for the safe use of pesticides, never have a law to protect the honeybee. It does mean that we believe the present arrangements give the public the protection it is entitled to expect from the use of pesticides in agriculture and food storage.

Discussion

Prof. H. G. H. Kearns started the discussion by asking whether, when an operator was tired and soaked in perspiration, he absorbed more or less insecticide through the skin. Dr. Barnes replied that one hazard in such a situation would be that his tiredness made the operator careless, but with regard to the presence of sweat he thought that any carry-off of material by the sweat would be offset by increased penetration. Mr. F. A. Squire enquired whether an insecticide was absorbed through the sweat pores, fat glands or through the skin itself, and Dr. Barnes was of the opinion, supported by findings at Porton, that the sweat glands were of little importance, most of the absorption taking place on a cell-to-cell basis through the skin tissues.

Dr. H. S. Darling enquired about the suitability of polythene gloves for protection, as Dr. Barnes had referred only to the use of rubber for that purpose. Dr. Miller reported that work had been carried out at Porton, which was in the process of being translated by the British Standards Institution into the form of recommendations; PVC, synthetic rubbers and natural rubber had been found to differ considerably in the amount of protection they offered with various materials, although it was the solvent and not the toxicant that caused the difference, for pure toxicants were unable to penetrate on their own. PVC gloves varied with the amount of plasticiser present, less protection being afforded when the plasticiser content was high.

Dr. E. F. Edson, taking the line of discussion away from the penetration of gloves, pointed out that in field use it was internal contamination that provided the main risk, and that then wettable powders were as hazardous as solutions, due to the emulsifier present in them. He emphasised that the inside of gloves should be cleaned as carefully as the outside, for that was where the skin contamination occurred. Sweat within the gloves could be overcome by the use of thin cotton gloves worn inside gloves of unsupported natural rubber, PVC or neoprene; gloves fashioned on a fabric base [*i.e.*, supported] should be avoided, as the textile tended to act as a wick and aided the penetration of toxicants.

Mr. C. E. Dyte referred to Dr. Miller's mention of the protection given to the public from insecticide residues under the Foods and Drugs Act, and asked if the meeting could be given some idea of the number of prosecutions that had been made as a result of residues having been found in foods as a consequence of spraying programmes or from accidental contamination in storage. Dr. Miller said that he was not competent to reply, but he believed that no such prosecutions had in fact been made. He pointed out that the problem was not exactly a novel one, as levels for arsenic in foodstuffs had been in force for something like fifty years. Mr. D. J. Colwill asked whether there were special arrangements for the following up of the Notification Scheme, to see that the recommended treatments were indeed used in the field, but Dr. Miller replied that there were no legal means for enforcing the Scheme. Dependence was placed on educational methods, and the grower had a natural inclination not to waste materials. There was also doubtless a certain amount of unofficial " policing " by the industry, to whom it was a matter of some importance that their products should be used correctly. Inspectors under the Foods and Drugs Act would no doubt come to learn of gross infringements, and there had been about a dozen prosecutions with regard to misuse of toxic materials.

Mr. R. F. W. Holliday sought the meeting's attitude towards the use of " voluntary precautions," especially as he quoted the case of demeton-methyl and dimethoate, both of which should be used with the same voluntary precautions, yet demeton-methyl came under Part III of the Act and dimethoate did not. He thought that the Ministry of Agriculture, Fisheries and Food should erase such anomalies. Dr. Miller pointed out that the regulations had been framed to cover about 160 chemicals used in agriculture in the United Kingdom, and that it was difficult to draw a line between different levels of toxicity. Demeton-methyl was regulated, and therefore the precautions were enforceable, whereas for dimethoate (although identical) they were not enforceable, and thus the line between levels of toxicity passed below demeton-methyl and above dimethoate.

Dr. E. F. Edson drew attention to the increasing use of low-volume sprays, from aircraft and as mists, and asked whether their use brought about risks any different from those incurred by the use of high-volume applications, to which Dr. Barnes replied that the operator took a greater risk with concentrated materials. Droplet size influenced the amount to which he would be exposed. There was no doubt that workers should clean their skin more often when working with concentrates, for such low-volume sprays were 5–10 times more concentrated than high-volume sprays. American work had shown that workers were receiving more parathion than the LD^{50}, but frequent breaks in the work, with washing, had prevented the occurrence of accidents.

Mr. W. Heeley suggested that the voluntary precautions were most important, with the education of the worker high on the list of requirements.

Speaking of experience with 0.5–0.75 per cent. dieldrin sprayed against Argentine ants in Western Australia and New South Wales, Mr. T. Greaves said that reliance was placed on the use of barrier creams and boiler suits, which suitably protected the operators against the toxicant though some were affected by the toluene solvent when spraying into the wind. Domestic animals had sometimes been killed. Dr. Barnes said that barrier creams were not popular in industry, but they had the virtue of ensuring that the user washed thoroughly after his work. Boiler suits probably gave adequate protection, but they were expensive to launder.

DISCUSSION ON RESEARCH ON STORED-PRODUCTS PESTS AND THEIR CONTROL

Chairman: Mr. G. V. B. Herford, c.b.e., *Director, Pest Infestation Laboratory*

The Chairman began by remarking that if the discussion required, it would be possible to compensate the slightly delayed start by continuing until 5.15 p.m. They were to be addressed by Dr. D. W. Hall, Tropical Liaison Officer of the Pest Infestation Laboratory, on the organisation of stored products work within the Commonwealth, then by Dr. J. A. Freeman on stored-products pests and international trade, and finally by Dr. Parkin, who would present a joint contribution from himself and Mr. A. A. Greene on some problems in the use of insecticides against stored-products pests.

The Organisation of Stored Products Work Within the Commonwealth

By Dr. D. W. Hall

Tropical Stored Produce Liaison Officer, Pest Infestation Laboratory, Slough

Recognition of the importance of post-harvest problems is more widespread within the Commonwealth now than ten years ago. During this period a number of countries have advanced from the stage of one agricultural entomologist, as a part-time activity attempting to minimise losses to produce, to a number of staff trained in stored products carrying out applied work and research.

This paper suggests the essential features of the organisation of stored products work overseas in tackling the practical problems of a tropical territory and for elucidating, through research, basic problems of the subject relevant to tropical conditions.

Stored products work starts on the farm and ends at the retailer/consumer level. The links in the " harvesting and marketing " chain between these extremes, are provided by traders and their stores, by processing procedures and by transportation (fig. 1). Thus this subject forms the hub of a wheel, on the periphery of which are the activities of agriculturalists, medical staff, economists, welfare workers, town planners, etc. In tropical territories the future rapid developments of urbanisation, from the present level in Africa and Asia of 6–8 per cent. of towns with populations above 100,000 to perhaps 22–48 per cent., which is the present figure for similar sized towns in Europe and North America, will necessitate careful study of the collection, storage, transportation and sale of produce.

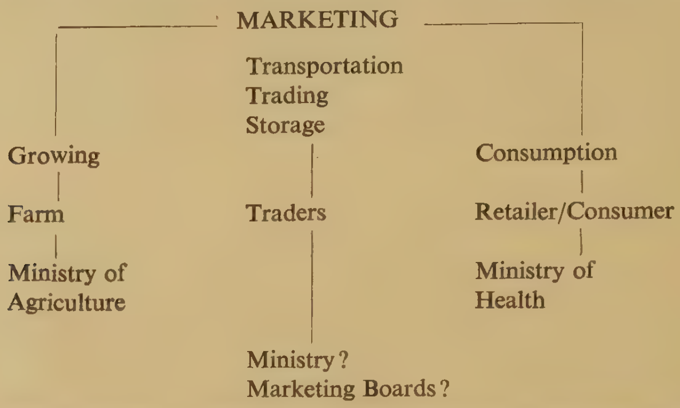

Fig. 1. The " marketing chain " of stored products and relevant Government Departments.

In most territories produce for export has been given more attention than other produce, by the establishment of special Government or quasi-Government organisations to collect, store, transport and sell on the world market. The demand of overseas buyers for improved quality standards forces the exporting country to be meticulously careful about its export produce. As a consequence the folly is soon realised of trying to organise the handling of produce for export without attention to other produce, locally grown for local consumption, or imported, which have to be handled on the same farm, in the same village, storage shed, mill or transport vehicle.

Advances in this field are affected by the attitude of the administrator and therefore every opportunity must be taken by the scientist to emphasise that protection of produce is vital to a territory and not only requires but warrants more than the general attention of commerce. The importance of the subject in the worldwide situation of increasing populations and low food standards in many areas and in the movement of vast quantities of produce in international trade is great enough, but the monetary value to a territory of the produce, both grown and imported (Table I), in itself warrants the expenditure of money in providing trained staff to ensure that produce is handled in an enlightened manner.

The subject of post-harvest problems is concerned not only with a study of insect pests but is a complex of a number of scientific and technical disciplines, including entomology, botany, chemistry, physics and engineering as well as sociology and economics, in all about twenty-two separate aspects of these subjects. All the aspects relevant to storage and handling of produce must therefore be considered, to obtain a concentrated effort in minimising losses and to ensure the efficient, hygienic and economic handling of produce.

Organisation

The organisation established to deal with the problems of this subject must have two aims in view—investigation of (1) the practical problems confronting a territory to give a quick economic solution and of (2) the impact of local conditions on the principles underlying storage problems. In considering both these aspects not only must maximum co-operation be given by the appropriate organisations within the overseas territory but also maximum

TABLE I

THE MONETARY VALUE (£ STERLING) OF PRODUCE HANDLED IN A NUMBER OF COMMONWEALTH COUNTRIES

Territory	Produce handled, £ sterling, millions
Gambia	4
Ghana	77
Nigeria	100
Sierra Leone	6
Kenya	19
Uganda	25
Tanganyika	13
Jamaica	8
Trinidad	8
Malaya	47
N. Borneo	9
Federation of Rhodesia and Nyasaland	34

use must be made of the existing information on the various aspects of the subject available at Government and other organisations in the more fully developed territories. The prime need today is for the application of existing knowledge, which if more widely applied would effect improvements out of all proportion to the cost.

I intend to deal, therefore, with the way in which the practical problems within a territory can be tackled and then with the organisation of overseas research.

Tackling the practical problems of a territory

In some territories the subject is being handled through the part-time interest of an agricultural entomologist or Government chemist, perhaps with the assistance of a man with years of practical experience in warehousekeeping but lacking an over-all grasp of the subject. In other territories one or more academically trained officers who have specialised in the subject are employed in carrying out applied experimental work and in addition in some areas there are pest control teams composed of local staff under the control of a practically minded operator. This is the position in territories such as Kenya, Southern Rhodesia, South Africa and Ghana. Within the Commonwealth, the territory in which the greatest number of staff is engaged on applied pest control work is Ghana, the biggest research organisation working under tropical conditions is the West African Stored Products Research Unit operating in Nigeria with a scientific complement of eleven officers.

There are four stages in setting about tackling the practical problems of a territory:—

(a) Drawing the attention of the authorities of the territory to the condition of the produce and the need for adequate and expert assistance in handling.
(b) Establishing Government specialists in the subject within the territory.
(c) Co-ordinating storage and infestation work within the territory.
(d) Assisting in the formulation of legislation.

It is usually impossible therefore for one man, whose appointment in the territory is primarily for pre-harvest investigations which in themselves are onerous, to advise and assist adequately on this subject and to train the various members of the community.

In all territories there are at least two Government Departments the officers of which are in close touch with the problems on the farm and at the retailer/consumer level, *viz.*, the Ministry of Agriculture and the Ministry of Health (fig. 1). Officers in these Departments must be knowledgeable on this subject and so assist the farmer and the shopkeeper in recognising the detrimental effect of unsound methods of harvesting, drying, processing, storing and transporting. In many territories, the gap between the farmer and the consumer is partially filled by a Produce Inspection Division of a Ministry, perhaps a Ministry of Commerce and Industry. However, it is extremely unusual to find this Division concerned with the quality and condition of *all* produce between the farm and the retailer/consumer level. Usually the three categories of produce, for local consumption, export and import are the concern of the three Ministries already mentioned, at specific points only and then only from specific angles. As shown in fig. 2, harvested produce for export is seldom the concern of Agricultural Department or Medical Department staff and similarly produce for local consumption is rarely examined by Produce Inspection staff. It is not uncommon for:—

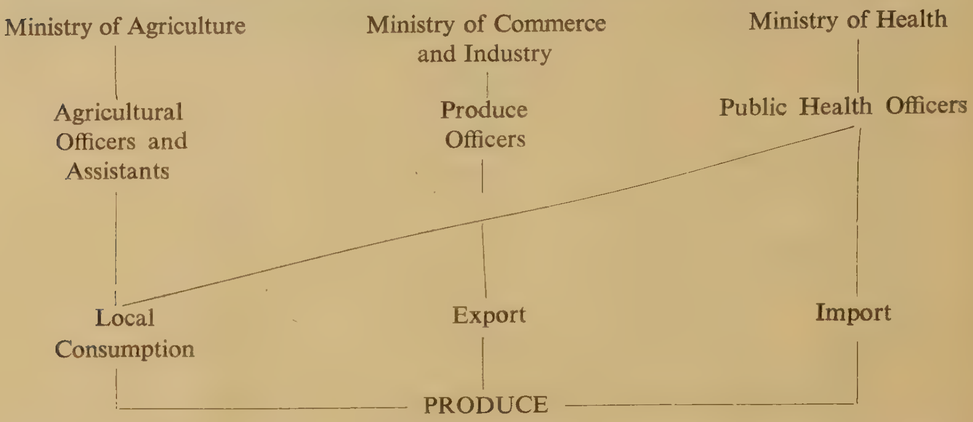

Fig. 2. The segregated roles of Overseas Government Departments concerned in produce inspection.

(a) produce stored on the farm for local consumption to be given less attention than produce for export,

(b) the quality of produce sold and consumed in the towns to be controlled generally by the process of condemning that which is unfit for human consumption—a stage which need not have been reached if advice had been given and control measures carried out earlier,

(c) the importance of contamination by insects, of produce for human consumption and for animal feed, in tropical territories to be insufficiently recognised by the Medical and Public Health authorities.

In every territory therefore there is the need for a co-ordination of the activities of officers of existing Departments to ensure that maximum attention is being given to this important subject at all levels. This can only be achieved if there is within each territory an organisation which can give adequate attention to the subject. The quantity and value of the produce of a territory will decide the size of the organisation required, but the full-time employment of at least one person is required by every territory. Where this is achieved improvements in the handling, storage and marketing of produce in an efficient manner with the active collaboration of the appropriate Departments become more likely.

A Government stored products organisation within a territory, which I shall call a Storage and Infestation Unit or Division, should be related to other Government organisations as indicated in fig. 3 and should have the following duties:—

(1) Acting as a liaison body on matters of storage and infestation primarily between the Ministry of Agriculture with its Agricultural Extension Service, Ministry of Commerce with its Produce Inspection Services and the Ministry of Health with its public health inspectors, to assist these organisations in recognising the existence of the problems and in solving them.

(2) Maintaining close liaison with Produce boards and produce dealers on their practical problems.

(3) Advising and assisting on all storage problems including initiating the introduction of legislation to encourage improvements in warehouse hygiene and to ensure the sensible and safe use of chemicals.

(4) Observing the efficiency of control methods under local conditions.

(5) Assisting in the general training of the staff of the appropriate Departments and commercial firms.

(6) Keeping abreast of the results of work being carried out in other territories by close liaison with the appropriate U.K. and overseas organisations.

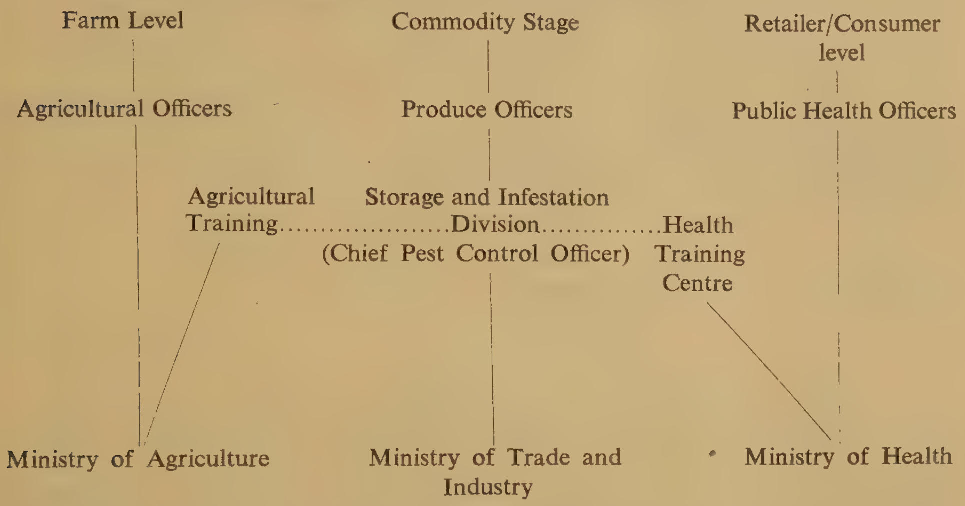

Fig. 3. Relationship of a Storage and Infestation Unit to other Government organisations and its role as a co-ordinating body.

The general pattern of an organisation capable of performing these duties could be as shown in fig. 4, where in the applied field a minimum staff of one academically trained officer in charge and two officers for inspection work is envisaged. This pattern is very similar to the one which has been recently initiated in Jamaica.

In a large country, the diversity of conditions between states could be dealt with by establishing a unit of this type in each state. However in India, I am informed the problem is being tackled through the activities of State and of Federal organisations. There, each State Department of Agriculture, through its entomologist, advises on problems of storage. The Federal Ministry of Food and Agriculture has three Departments concerned with storage problems—a Department of Extension which has an agricultural branch responsible for development work at the farm level, a Department of Storage dealing with problems at large storage centres and with imports, and a Department of Plant Protection, Quarantine and Storage which has a Plant Protection Division concerned with general advice on storage and a Storage and Locusts Division concerned with advice on storage to farmers only. There is also a Food Grains Storage Advisory Committee which is intended to familiarise the populace with modern scientific techniques of grain storage, and a Central Institute which gives training and undertakes research in problems relating to the handling of grain.

Research

Whenever practical problems are investigated it is inevitable that research problems occur which require the uninterrupted attention of trained academic staff. Projects of a fairly straightforward and superficial nature on occasion can be undertaken by the applied organisation but it is impossible for such an organisation to supervise the day to day storage problems and to do research work. It is therefore essential for facilities to exist whereby research investigations can be carried out as a separate operation. It is nevertheless important to have the research and the applied work extremely closely dovetailed and this is best achieved by having the officers concerned with each aspect operating within the same organisation (fig. 4).

In the larger territories the work of a Storage and Infestation Unit or Division will require the full time employment of at least one and most probably two research workers, to investigate problems such as the bionomics of an insect species in relation to the effective use of contact insecticides or the distribution of a fumigant throughout a bulk of produce to

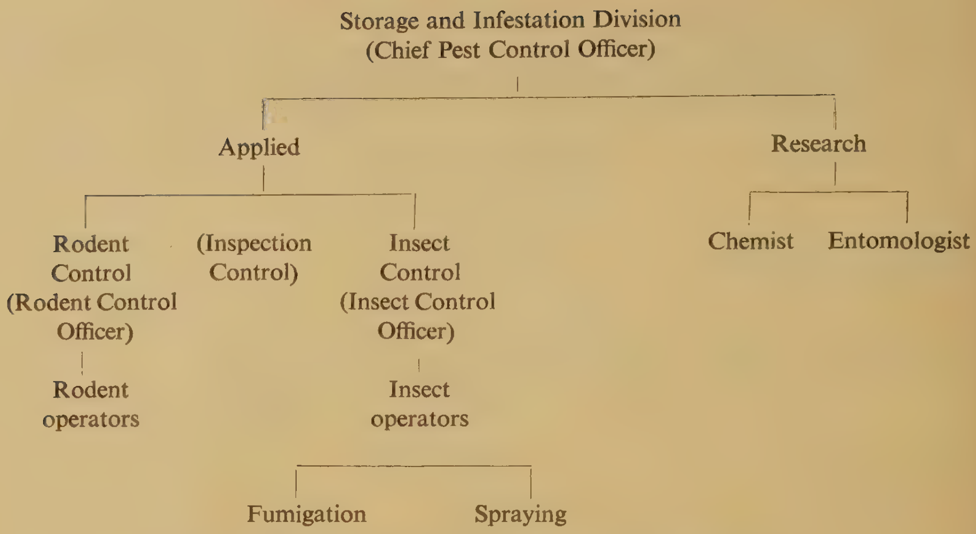
Storage and Infestation Division
(Chief Pest Control Officer)
Applied
Research
Rodent Control (Rodent Control Officer)
(Inspection Control)
Insect Control (Insect Control Officer)
Chemist
Entomologist
Rodent operators
Insect operators
Fumigation
Spraying

Fig. 4. Suggested complement of a Storage and Infestation Unit.

which the fumigant has been applied in a particular manner. In territories which cannot afford to employ research staff, much time, effort and money can be inefficiently expended by the applied staff from lack of sufficient local basic information. As far as the British Colonies are concerned, the temporary employment of trained staff on a specific project is effected through the existence of the Pool of Stored Products Workers, financed by Colonial Development and Welfare money, a Pool from which a Colony (financially embarrassed or otherwise) can be provided with assistance in tackling its applied as well as its research problems. This Pool is based at the Pest Infestation Laboratory, Slough. It can be used also as a reservoir from which a permanent stored products post within a Colonial territory can be filled.

The importance of being able to obtain advice on overseas problems from research laboratories in the U.K. has been stressed by overseas workers and the volume of requests received emphasises this point. Many of the requests for help are received through the Tropical Liaison organisation in the U.K.* The staff of the laboratories concerned in the U.K. are unable to give adequate advice, however, without much more research of a basic nature being carried out under tropical conditions to provide a background of scientific knowledge on which advice on problems in many different territories can be based. The appropriate U.K. organisations therefore should be provided with the powers to send staff overseas to carry out experimental work of a fundamental nature. This presupposes the existence or creation of research centres overseas with the necessary facilities. Such centres in fact exist in some places—the laboratories of the West African Stored Products Research Unit at Kano, Ibadan and Port Harcourt, of the Colonial Pesticide Research Unit at Arusha, etc.

There are many administrative problems linked with development on these lines, particularly with respect to finance, but since all the countries in the Commonwealth could benefit from basic studies under tropical conditions it should be possible to overcome administrative problems. An attempt should be made now to appoint a Commonwealth Committee with powers to organise and finance fundamental research on this subject within the Commonwealth. Member Governments would perhaps be willing to contribute financially to storage and infestation research investigations overseas.

The results of scientific investigation on basic problems are universally useful and therefore the interest of the Food and Agricultural Organisation of the United Nations is assured in any work of a basic nature. This interest might perhaps eventually extend to active financial participation in certain fundamental work from which many territories could benefit. Co-ordination including the financing of stored products research on an international basis is urgently required but this can hardly be expected at this juncture when even within the Commonwealth a unified policy has not yet been achieved.

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* The Tropical Liaison Officer and staff are based at the Pest Infestation Laboratory, Slough and also function at the Tropical Products Institute and the Colonial Office. They are in close touch with the Tropical Liaison Sections of the Building Research Station and the Road Research Laboratory, with the Commonwealth Liaison Officer of the National Institute of Agricultural Engineering and with the Colonial Rodent Liaison Officer at the Ministry of Agriculture, Fisheries and Food, all of whom can contribute to the subject of post-harvest problems.

Great Britain and the Commonwealth are in advance of other countries in the investigation of post-harvest problems. They will only remain so if the scientific staff in the tropical territories is increased in numbers, the specialists in the U.K. carry their experimental work into the tropical conditions and there is close collaboration between all parties concerned. This will ensure both that local problems are tackled and that there is a steady advance in obtaining scientific knowledge from tropical conditions.

Stored Products Pests and International Trade

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In many countries the control of storage insects is looked on primarily as a means of safeguarding agricultural products during periods of long-term storage, especially where Governments have established famine reserves, or where official marketing boards and similar organisations have a direct interest in preventing losses. With few exceptions, particularly Canada and U.S.A., infestation in export crops, even when these have been graded, has been regarded as a commercial matter to be settled as between buyer and seller, Government intervention being confined to such inspection as is necessary to provide Plant Health Certificates, when these are required by the importing country.

Of recent years, however, an increasing number of countries have been demanding that imported agricultural products, especially those to be used for human food, should be almost completely free from living or dead insects and this in turn has led to a greater interest in control by producing countries. This demand has been based not only on grounds of public health and plant protection, but also on commercial considerations since an increasing proportion of food manufacturers and traders prefers to use uninfested and undamaged raw materials, even if these initially cost a little more.

The following are the principal reasons why agricultural products carried in international trade should be as free as possible from infestation.

Firstly commodities, especially foodstuffs, which are attacked and damaged by storage insects represent a waste of the resources used in their production; are of lower commercial value, bringing a lower return to the producer; and cause the importer more annoyance and expense than sound goods.

Secondly, their carriage throughout the world results not only in continued damage to the goods in transit and storage, but also to cross infestation of other commodities and to residual infestation in ships and warehouses. This residual infestation may persist for long periods in ships and cause infestations in goods carried many years later (Freeman, 1950).

Thirdly, traffic in infested goods, by continued reintroduction of pests, may seriously prejudice efforts being made within importing countries to control indigenous infestation. One example is *Oryzaephilus surinamensis* (L.), a pest of increasing importance in home produced grain in the United Kingdom (Freeman, 1959). This species is one of the most common on imported foodstuffs and is particularly liable to be carried to farm granaries on animal feeding stuffs.

Fourthly, there is the risk of introduction and establishment of pests in new areas. Examples of such spread in recent times are the khapra beetle, *Trogoderma granarium* Everts., into the U.S.A. and Africa south of the Sahara (Howe, 1958); the Australian carpet beetle, *Anthrenocerus australis* (Hope), from Australia to the U.K. (Bezant, 1957) and the nut moth, *Aphomia gularis* (Zell.), from China to Europe and N. America, though not as yet to apparently suitable environments in the Southern hemisphere (Smith, 1956). In assessing the risk of establishment of storage pests one must not only consider natural climatic conditions, but also the artificial ones in industrial buildings. Thus *Trogoderma granarium* is quite unable to breed in unheated buildings in the U.K. but is a serious pest in malt, which is normally stored under hot and dry conditions in bins round the kilns. The indirect spread of *Trogoderma* is illustrated by the fact that one of the outbreaks of *Trogoderma* in an East African brewery was due to its introduction in infested malt from the United Kingdom.

Infestation as it Affects the Importing Country

With present developments of control measures which can be readily used in producing countries, importing countries expect commodities to be sufficiently free from infestation that no control should be necessary on arrival. However, the degree to which infestation can be tolerated in commodities on arrival in the United Kingdom depends on the kind of commodity, the use to which it is to be put and where it is to be sent, and the likely period of storage. These considerations will also apply generally to other importing countries, with variations according to circumstances, especially as regards plant health and public health.

In general, little or no infestation can be tolerated in dried fruit, edible nuts, desiccated coconut, manufactured foods, spices, pulses, dried milk and flour, all of which are likely to pass to the consumer with little or no processing of a kind which will remove living or dead insects. Furthermore little infestation can be tolerated in commodities such as cocoa beans where there is a risk of cross infestation of finished products in the factory or where the amount of contamination by insect fragments must be kept to a minimum.

Although the flour miller can use infested and damaged wheat, he prefers sound undamaged grain, as it gives a greater yield of flour and can be stored safely. Some recent shipments of Australian and Argentine wheat taken into mills as complete cargoes and unlikely to be entirely consumed for about six months have been found infested on arrival to such an extent that fumigation was necessary.

A higher degree of infestation can be tolerated in commodities which will be processed fairly rapidly by methods which kill the insects. Such commodities include oilseeds, oilcakes and other raw materials for manufacture of compound feeding stuffs. If such commodities are to be sent inland and there is the risk that they may carry insects to agricultural merchants and farms, control measures should be applied in the ports. Even so it has been shown that the yield and quality of oil from sound groundnuts are greater than from those which are infested (Hall, 1954). Similar considerations apply to the extraction of starch and oil from maize.

The difficulties for an importer in handling or disposing of infested imports may be such that if commodities tend to be regularly infested and need fumigation, screening, rebagging or other treatment, he will look for a source of uninfested goods. Where competition is severe and many sources of supply of equal quality are available the uninfested goods may well obtain the preference. This is tending to show itself particularly with nuts for confectionery and with dried fruit.

Infestation Control in Country of Origin

There are three principal ways in which the amount of infestation and the extent of damage in goods at time of export can be reduced.

(1) *Commercial Contracts*

Commercial arrangements between buyer and seller can be made under which the contract provides for freedom from infestation or damage or allows only a limited amount. As an example, beans for canning are generally purchased under a contract which provides that they shall be free, at time of arrival in the United Kingdom, not only from obvious damage and living adults but also from larvae within the beans. Cocoa beans from Ghana are purchased by American and Russian buyers under contracts which specify not more than ten living insects per bag at time of arrival. This is assured by fumigation at time of shipment. Compliance with contract specifications does not normally involve intervention by Government officials, the necessary sampling and testing being done by firms of cargo superintendents. Much international trade, for example in grain, feeding stuffs, oilseeds and bones, is carried out under commercial contracts which seldom take any account of infestation. The risk to the buyer or seller of having to do something to control infestation may be covered by insurance. This is done, for example, for groundnut kernels exported from Central Africa through Beira, and for flour exported from Australia. Some years ago infestation in a single shipment of Australian flour cost the insurance company £16,000.

In some instances the sellers carry out fumigation at or before time of export, with the implication that the goods are free from infestation at that time. This has been done for walnuts from India, maize from Rhodesia, wheat from Turkey and currants from Greece. Such a procedure is not infrequently vitiated by the rapid reinfestation of fumigated goods stored in infested warehouses before shipment or by cross infestation on ships. Many merchants, however, erroneously believe that fumigation gives lasting protection. Grain merchants in the United Kingdom were surprised some years ago to find considerable infestation in maize from East Africa which they had purchased as " fumigated maize." The maize had actually been treated some nine months before shipment and had become reinfested in the interval.

(2) *Grading or Quality Control*

Grading or quality control schemes, under which all, or certain classes of commodities exported, must conform to certain standards which are enforced by Government officials, may include tolerances for living insects and insect damage (Freeman, 1957, 1958). Thus, wheat may not be exported from Canada if any living insects are found at time of grading during loading into a ship; no living or dead insects may be present in rice exported from the U.S.A.; the tolerance for " weevil," *Sitophilus oryzae* (L.), *S. granarius* (L.) and *Rhyzopertha dominica* (F.), in wheat and maize under the United States Grain Standards Act is two per kilogram; a similar, though stricter tolerance is applied to maize and maize products exported from the Union of South Africa and maize which does not conform is fumigated before shipment. Tolerances for insect damage occur in the Argentine grain grading system, under which price penalties are made if the " picado " figure (*i.e.*, the weight in grams of insect-bored grain per 100 g. sample) exceeds the limits of 1 per cent. for wheat and 3 per cent. for maize. Recent shipments of old crop maize have had up to 40 per cent. " picado " shown on the export certificates, and on arrival in the U.K. have shown correspondingly high active infestation. Grain is seldom fumigated in Argentina before shipment. Insect damage enters into the grading systems for cocoa beans exported from Ghana and Nigeria and should not exceed 2–3 weevily beans per 100 for Grade I (Cranham, 1960). Such grading and inspection schemes can ensure that no produce which is obviously infested or damaged is allowed to be exported.

The extent to which such schemes are successful depends very much on the efficiency of the sampling and inspection techniques. One major disadvantage of present methods is that only adult insects, readily detectable by sieving, are taken into account, and larval infestation within grains or beans is neglected. This problem has been receiving particular attention in the U.S.A., where wheat, placed in the highest grade under the Grain Standards Act specifications, has been refused by millers on further testing owing to the hidden infestation being so high that they could not make flour which would meet the standards of insect particle contamination laid down by the Food and Drug Administration.

A particular example occurred some years ago when top grade peas exported from the United States were found considerably infested and damaged on arrival in the U.K. Subsequent investigation showed that the peas, infested in the field by *Bruchus pisorum* L., had been properly graded shortly after harvest when the larvae were within them and the number of adults was less than the tolerance. During the period between grading and arrival in the U.K., the larvae developed and adults emerged.

Some countries include compulsory fumigation, under the supervision of Plant Protection Officials, as part of quality control schemes. This is the case for certain pulses and dried fruit exported from Algeria (Freeman, 1957, 1958).

(3) *Plant Protection*

Plant protection legislation may provide the means by which control of storage pests can be effected before export, either because of a need to meet the requirements of the importing country, or, exceptionally, of the exporting country itself. Examples of prohibition of entry of storage insects, either absolutely or under conditions are as follows:

(a) Chile	*Sitotroga cerealella* (Ol.)
(b) Turkey, Tanganyika, Zanzibar, Kenya	*Trogoderma granarium* Everts.
(c) Egypt	*Araecerus fasciculatus* (Deg.) (cocoa beans)
(d) Hungary	*Acanthoscelides obtectus* (Say) *Bruchus pisorum* (L.) *Sitophilus oryzae* (L.) *Sitophilus granarius* (L.)
(e) U.S.S.R.	*Callosobruchus chinensis* (L.) *C. 4–maculatus* (F.) *Caulophilus latinasus* (Say)

(f) Recent legislation in West Germany lays down general quarantines against certain storage pests, but this does not come into effect until 1965.

(g) Strict requirements in regard to infestation of rice and beans imported into Japan, Israel, Czechoslovakia and the U.S.S.R. have led to much treatment of such cargoes in exporting countries immediately before shipment.

The plant health legislation of Brazil requires fumigation of all export maize, pulses and cottonseed, but not cocoa beans.

In general the value of plant health certificates issued on the basis of inspection of stored products is less for storage insects than for field crop pests, owing to the far greater risk of reinfestation. Such certificates should be issued either immediately before shipment or subject to reservations regarding the subsequent storage of the commodities.

Infestation During Shipment

Precautions taken under commercial contracts, grading schemes or plant health regulations may be vitiated if the holds of the ships into which goods are stowed have insects remaining from previous cargoes, or if insects move from other infested cargo during the voyage.

Inspection and Treatment of Empty Holds

The need to ensure that pest-free goods occupy clean holds was first recognised by Canada, where all ships carrying cereals, cereal products, oilseeds and oilseed products must obtain clearance by Plant Protection Inspectors before loading commences or be treated at the shipowner's expense in accordance with their requirements (Freeman, 1958). Similar provisions enforced by Grain Grading Inspectors apply to shipments of grain graded under the provisions of the United States Grain Standards Act.

Ships are inspected by the Infestation Control inspectors of the Ministry of Agriculture, Fisheries and Food and of the Department of Agriculture for Scotland during and after unloading in ports in the United Kingdom and recommendations made in writing (Certificate of Inspection of Holds for Infestation) to masters, owners and agents for the control of residual infestation. The recommendations range from cleaning alone, to cleaning with treatment by smokes (DDT, or Lindane or the two in combination), or sprays (usually malathion emulsions or water dispersible powders) applied by powered knapsack sprayers, for superficial infestations, to fumigation with methyl bromide or hydrogen cyanide for severe general infestations. Information regarding such infestations and the steps taken to deal with them in ships going to certain countries is regularly sent to those countries overseas which maintain official services for the inspection of ships at time of loading, such as Canada and the United States.

Many shipowners now carry out regular spraying or smoke treatment of empty holds, irrespective of specific recommendations or requirements, as they have appreciated the advantage of being able to demonstrate that they have taken all possible precautions, in the event of claims being made by owners of goods, which show infestation at the end of a voyage when apparently quite clear at time of loading. Thus the holds of ships carrying groundnut kernels from South Africa, which are commercially fumigated immediately before shipment, are sprayed with lindane formulations before the groundnuts are loaded and the surface of the nuts sprayed after loading. As far as possible other infested commodities such as oilcake and maize products are stored away from the groundnuts.

Cross and Residual Infestations

The folly of stowing tea, groundnut cake and cottonseed together was demonstrated in 1956 when 8,000 chests of tea from East Africa became contaminated during the voyage with *Tribolium castaneum*. On arrival in the U.K. the tea had to be fumigated and reconditioned at a cost of £3,000, paid by the shipping company, which accepted liability.

Residual infestation may persist for many years in residues of previous cargoes on deck beams, behind wooden sheathings to warm bulkheads and in pipe casings. This is particularly the case for *Trogoderma granarium*, which is known to have been established in one ship for at least the seven years prior to June 1957 (Turtle and Freeman, 1960). The Infestation Control Laboratory now has records of some 150 ships in which *Trogoderma granarium* has been found since 1957; in view of the difficulty of killing this insect it is quite likely that many of these ships still harbour this species. So long as ships remain on a regular " infested " run there is little risk of such residual infestations resulting in unexpected spread. However, special precautions had to be taken during 1959 when a ship, known to have carried a cargo infested with *Trogoderma granarium* from the Far East, was chartered for a voyage to East Africa.

Development of Infestation in Infested Cargo

If insects are present in goods at time of shipment they will normally continue to develop during the voyage, as the mass of goods retains its original loading temperature for long periods. Heating in bulk grain is a common result of infestation and can result in consequent condensation and caking at the surface. Such infestations may be encouraged by local sources of heat in ships such as engine room bulkheads, propeller shaft tunnels and steam or hot water pipes (Freeman, 1952, 1953). Such heating is not uncommon in cargoes of grain from Argentina and Australia and occurs from time to time in Canadian wheat shipped from Vancouver. The cause of heating of the Canadian wheat is almost exclusively the development of small populations of *Cryptolestes ferrugineus* (Steph.) (Freeman, 1952, 1953).

In-ship Fumigation of Hold and Cargo

Where commodities themselves need treatment it is possible in certain circumstances to fumigate the goods in the loaded holds of ocean ships. Such treatments deal not only with insects in the cargo but also with any remaining from previous cargoes. This technique is very useful where proper facilities for treatment are not available on shore. Such in-ship treatments were first done for maize in Brazil, but have also been carried out in the United States (grain), Mexico (oilcake), Greece, Turkey and Pakistan (grain), Burma (rice, beans) and Spain (rice), and in ships running between the Philippines and the U.S.A. (copra).

TREATMENTS OF CARGO IN SHIPS

(a) Chlorinated hydrocarbon mixtures poured or pumped on to exposed surface of bulk grain.

United States	Wheat
Greece, Turkey, Pakistan	Wheat

(b) " Phostoxin " tablets added to grain at time of loading.

Turkey	Wheat

(c) Methyl bromide vapourised into free space above cargo in hold.

Brazil	Maize
Mexico	Cottonseed cake
Burma	Rice, beans
Spain	Rice
U.K.	Small quantities of cargo in compartments

(d) Methyl bromide vaporised into free space above grain in lower hold and circulated through grain by fan and duct system.

U.S.A.	Wheat in store ships

(e) Ethylene oxide, carbon dioxide mixture circulated through holds by ship's mechanical ventilation system.

During voyages from Philippines to U.S.A. ..	Copra

Although some studies of efficiency of this technique have been made, especially for treatment of grain in store ships in the U.S.A. by forced circulation of methyl bromide (Phillips, 1955), more work is needed, especially on the distribution of fumigant by methods of gas sampling, in cargo normally stowed in the various different ways used commercially. Most assessments have hitherto been based on test insects which have necessarily had to be placed in accessible positions.

Conclusions

The application of proper measures of control at and before time of export both to goods and to the ships which carry them, should lead to a progressive diminution in the need to treat commodities on arrival in importing countries. Proper organisation with skilled personnel is necessary for carrying out inspection and control, and the organisation needs to be backed by research carried out locally.

The application of the results of research by the West African Stored Products Research Unit in Nigeria and other British West African territories has resulted in a decrease in infestation of groundnuts, groundnut cake and cocoa beans on arrival in the U.K., especially in the incidence of *Trogoderma granarium* on the two former. This has shown a more or less continuous fall since 1949 when over 50 per cent. of all shipments were infested by this species. During 1959 it was found only six times and so far in 1960 it has not been found at all. During the same period, however, produce, principally oilcake, rice and rice products from Burma, where little has been done to control infestation during storage, and where no research is done, has continued to arrive with a general heavy level of infestation. Of particular interest is the increase in incidence of *T. granarium* at a time when that on Nigerian produce was declining (fig. 1).

Unless fumigation of all exports of a particular kind is adopted, as has been mentioned for Algeria, it is necessary to carry out inspections to determine tolerances for infestation. These can conveniently form part of official grading schemes, which can be applied compulsorily to all exported produce. It is not difficult to obtain agreement on what constitutes a serious infestation but difficulties arise at low levels, especially when conditions of carriage by sea are such that populations which are not readily apparent at time of loading increase during a voyage to substantial numbers at time of discharge. This constitutes a current problem with Australian wheat shipments to the United Kingdom. Quick and simple tests are particularly needed for the detection of internal infestation of grain, pulses and cocoa beans. Agreement is also needed in some instances on the relative importance of species. Thus *Lasioderma serricorne* is the major pest of cocoa beans in West Africa, whereas *Ephestia cautella* is of less importance. On arrival in the U.K., however, the occurrence of the latter is regarded as of considerably greater moment than of *Lasioderma*, which soon dies in unheated storage. Any system of insect tolerance at time of export must take account of the attitude of the importing country.

More work is needed on the lines of that carried out by Matthews (1958) on the conditions which affect the development of insects in cargoes during carriage by sea, on methods of control of residual infestation and, in particular, on the fumigation of loaded holds. Attention also needs to be given to the improvement in the design of ships to eliminate places where cargo residues accumulate and from which they are difficult to remove. In this regard the use of oil tankers and bulk carriers for grain is a welcome development because of the absence of ledges.

The measures proposed can be applied without difficulty in countries which export through their own ports. Where goods must be exported through another country, the problem is more difficult. During 1959 it was found that groundnut kernels from N. Rhodesia and Nyasaland were arriving in the U.K. with regular moderate infestation by

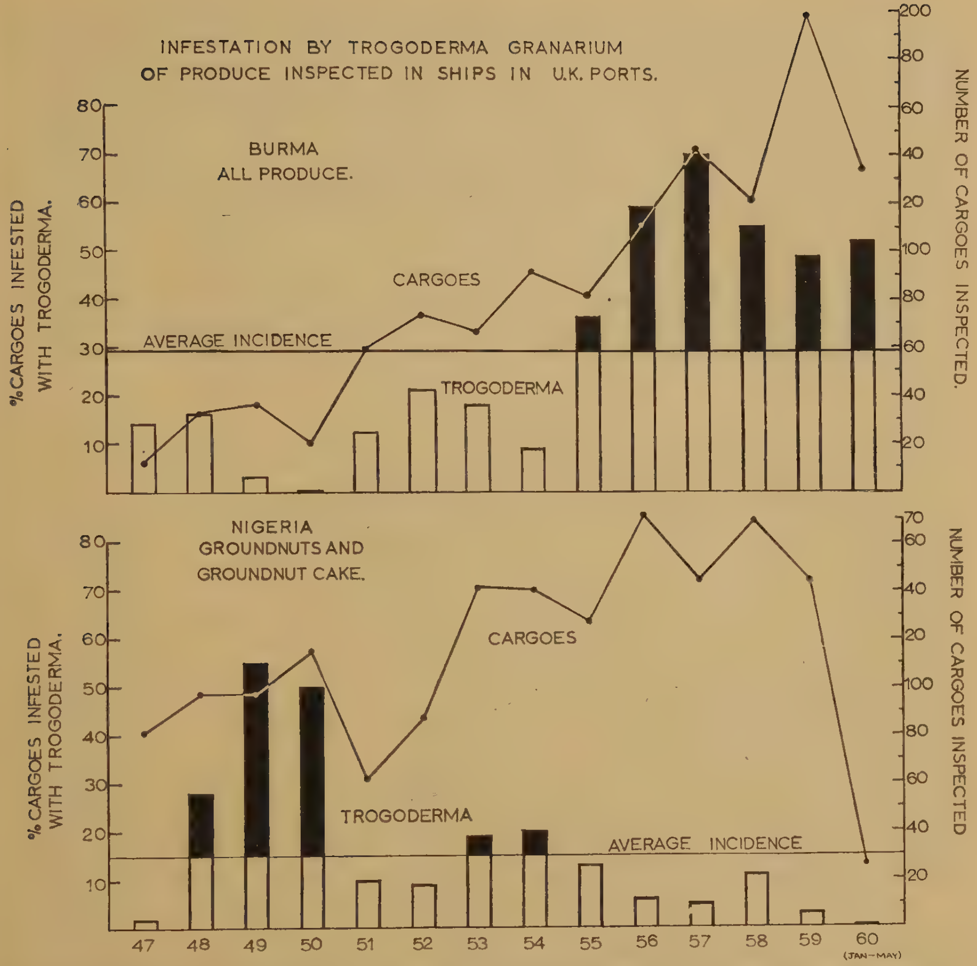

Fig. 1. Incidence of *Trogoderma granarium* on produce from Burma and Nigeria inspected on arrival in the United Kingdom, 1947–1960.

Notes 1. Based on inspections made by the Infestation Control organisations of the Ministry of Agriculture, Fisheries and Food and by the Department of Agriculture for Scotland.

2. Nigerian data 1947–1952 from Howe and Freeman (1955).

3. Nigerian figures for 1947–1952 apply to groundnuts only; 1953–1960 to groundnuts and groundnut cake. Shipments of the latter before 1953 were negligible.

4. Figures for 1960 cover January to May.

5. Produce from Burma includes rice, ricebran, oilcake and pulses.

Ephestia cautella, sufficient on occasion to justify fumigation. Investigations indicated that although many parcels of Rhodesian kernels were fumigated with methyl bromide under sheets on arrival in warehouse in Beira, Mozambique, they were apparently becoming re-infested before shipment. The longer the period before shipment, the heavier was the infestation seen on arrival in the U.K. There was no evidence in most instances of any infestation arising from the ships. Groundnuts, fumigated in Nyasaland before they were railed to Beira, were also arriving infested in the United Kingdom. Similar problems had arisen with Rhodesian maize exported through Beira. The matter of infestation of groundnut kernels was taken up with the Head of Stored Products Investigations in Lisbon, and a mission sent to Mozambique also visited the Federation of Rhodesia and Nyasaland and the Union of South Africa to study the general problem of exports through Beira and Lourenço Marques. It is hoped that the result will be a closer working arrangement between the hinterland countries and Mozambique so that proper protective measures may be taken all along the line.

Although measures taken by individual countries, traders and shipowners or limited international co-operation on these lines go part of the way, their efforts are liable to be frustrated by the continued traffic in infested commodities which have not been treated. For this reason F.A.O. has drawn up a draft supplement to the International Plant Protection Convention to deal specifically with the problem of international trade in infested foodstuffs. This would place an obligation on exporting countries to prevent export of obviously infested foods and to see that residual infestation in ships is controlled; importing countries would be expected to refuse entry to infested foods or to accept them under safeguards. Discussions on the draft agreement should take place in 1961.

The control of infestation in stored products moving in international trade depends on full co-operation between all interests involved, and not least upon an acceptance by the countries which produce and export agricultural products, of a responsibility to ship uninfested goods in clean ships.

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Some Practical Problems in the Use of Contact Insecticides Against Stored-Product Insects

By Dr. E. A. Parkin and Mr. A. A. Green
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In recent years increased concern about the loss of stored produce through insect infestation, particularly in the warmer parts of the world, has led to greater interest in and use of control measures. Among the available measures stress must always be placed first upon clean and properly organised storage but this has normally to be supplemented by the application of chemicals.

Fumigation can effect quick and complete disinfestation but the greater persistence of contact insecticides is often needed to protect fumigated stocks against rapid reinfestation or to protect those goods put into store in an initially clean condition.

It is the object of this paper to raise for discussion a number of points relating particularly to field testing and the application of control measures against stored-product insects.

A wide knowledge of insect biology, and particularly of insect habits, is necessary to take advantage of any vulnerable phase in the life cycle. Sometimes no such phase is apparent but a careful biological study has, in general, proved to be an essential aid to successful practical control. For example, the control of *Ephestia elutella* (Hb.) in United Kingdom warehouses is now based on the timing of sprays to combat the flying adult moths or the migrating caterpillars. A corresponding knowledge of *Ephestia cautella* (Wlk.) in tropical stowages has shown that the caterpillars do not migrate in so vigorous or exposed a manner and that reliance must be placed on control of the adults, especially by fogging during the main flight period at dusk. Similarly, the control of *Caryedon gonagra* (F.) in undecorticated groundnuts in the Gambia by surface treatment of the loose heaps of nuts with lindane dust has been dependent upon the biological observation that under these conditions of storage this beetle breeds only in the superficial layers (Green, 1959).

Much of the advice given on the choice and application of contact insecticides is naturally based upon the results of laboratory research. Experience has taught, however, that results obtained in the precise and closely controlled laboratory test cannot always be applied to the conditions of practice with its much more variable human, environmental and commercial factors.

What is learned from the laboratory testing is usually of considerable value in forecasting the likely efficacy of compounds used in practice. For instance, laboratory tests predicted the efficacy to be expected from the use of malathion formulations to control *Oryzaephilus surinamensis* (L.), *Tribolium castaneum* (Hbst.) and a number of other species (Parkin, 1958); the value of this insecticide has now been confirmed by field trials and usage.

A more specific investigation of the value of malathion water dispersible powder application to sacks for prevention of infestation of decorticated groundnuts by *T. castaneum* showed, however, the caution that is often necessary in judging the importance of " scale " or " size " in control measures. Experiments with small sacks exposed to infestation by beetles showed that malathion at 80 mg. per sq. ft. applied monthly gave virtually complete protection (Green and Kane, 1959). The treatment did not prevent a few beetles from penetrating into the groundnuts and breeding but all insects were killed within one breeding cycle. When the trial was repeated with full-sized sacks, breeding was continuous and large infestations developed. Further tests indicated that, to a depth of 2–3 inches from the treated sacking, successful breeding was prevented by the vapour toxicity of the malathion in the intergranular spaces and by some absorption into the nuts (Anon., 1960). The dose of malathion successful in the small-scale laboratory test would therefore not ensure control in practice.

A specialised knowledge of commercial applicators is required if the machine most suited to a particular job is to be selected from the range available. We would like to draw special attention to the need for the efficient agitation of water dispersible powders. A water dispersible powder that suspends none too well and lack of agitation in a power-operated knapsack sprayer can be shown to result in a few minutes spraying at too high a concentration followed by a period in which only water is sprayed, and ending with a burst of sludge. Efficient agitation will prevent this unevenness (Bills and Green, 1960). If an unsuitable applicator must be used, simple sampling of the spray on a time basis into a set of tubes of equal volume will quickly indicate for how long the apparatus can be reasonably used without the need to shake or recharge.

Moreover, in practical spraying it is often not realised how much the output rate can be affected by the height at which the nozzle is held in relation to the height of the liquid in the reservoir, especially with applicators utilising gravity or only low pressure feed. The same applies to distance and angle between spray nozzle and target.

Thoroughness in application pays dividends, not only in the greater immediate control achieved, but also in the greater spacing of repetitive treatments with consequent saving in insecticide and labour. An excellent example of this has come from our recent work in the London docks where monthly applications by the Laboratory staff of half the previously recommended dose of pyrethrins has given 100 per cent. protection of cocoa in bags against infestation by endemic *E. elutella*, whereas treatments in neighbouring stowages by the wharfinger's staff failed to prevent very heavy infestations and ultimate impressive migrations of larvae (Green and Kane, 1960).

In contemplating practical control measures, especially when local unskilled labour is to be used, the difficulties often seem all too great, but it is heartening to find how they melt away in the face of vigorous organisation. We are indebted to Mr. J. Rawnsley for permission to mention his excellent campaign for control of *E. cautella* in Ghana cocoa warehouses by fogging with pyrethrum spray every evening during the flight season of the moths. Local labour has been trained to operate portable thermal fog generators, each machine being filled by the supervisor with the requisite amount of spray liquid for a particular stowage and then run to exhaustion during the application. All the treatment is given from the outside of the buildings through specially cut apertures in the doors.

There has been of late increasing reference by stored-product workers in the field to the occurrence of possibly resistant strains of insects, but insufficient information has usually been available to eliminate the possibility of poor application as the main cause of the apparent failure of treatment. Poor application in practice or the steady decline in toxicity of a well applied dose of insecticide will lead to some insects receiving sub-lethal doses and give suitable circumstances for the selection of resistant strains.

There would seem to be no reason why stored-product insects should not develop resistance to the insecticides in current use. Laboratory investigations are very slow and tedious and negative results can be interpreted only as meaning that the capacity for developing resistance was not present in the particular sample of insects with which the investigation was started. Several laboratory attempts have resulted in no more than vigour tolerance, but a strain of *Sitophilus granarius* (L.) has been produced with a factor of ×18 in its resistance to pyrethrins by selection in 17 out of 22 generations in the course of five years (Parkin and Lloyd, 1960). Since then the pyrethrum resistance has nearly doubled as a result of two more selections in the following three generations.

Large quantities of lindane formulations have been used in recent years for rice weevil control and there have been many suggestions of the occurrence of induced resistance to this insecticide. So far, however, there has not been any fully acceptable proof of lindane resistance in this species significantly passing the level that might be regarded as vigour tolerance. The position has been complicated by the fairly recent separation of the species *Sitophilus sasakii* (Tak.) from *S. oryzae* (L.), because preliminary laboratory evidence suggests that the former species either has a greater basic resistance to lindane or has a greater potentiality for developing it. The Pest Infestation Laboratory strain of *S. oryzae* has not exceeded ×2·5 in selection for 16 generations and therefore does not seem to possess the genetic characteristics necessary for the development of high resistance to this insecticide. We are at present about to embark upon an investigation into the lindane resistance of field strains of the rice weevil and would be glad to receive a few hundred beetles from any situation where there are reasonable grounds for suspecting the presence of resistance. It would also be of interest to receive strains which almost certainly have not been exposed to lindane so that the variability of the " normal " may be measured. We are suspicious that our laboratory inbred strain is unusually susceptible to lindane.

Contact insecticides cannot be used on or near stored products without due regard to the possibilities of taint or contamination. Facilities for the chemical determination of residues are still very meagre although definitely, albeit slowly, expanding. The chemist has to take on trust the samples he receives and it is, therefore, essential that they be sufficiently carefully drawn and sufficiently numerous to represent reasonably the situation being studied; on the other hand, they must not be so numerous as to throw an unfair burden on the analyst, for chemical assays are difficult and time-consuming. The results are likely to show variability, much of which can sometimes be traced to lack of sufficient care in application of the treatment. The utmost uniformity of dosage must usually be striven for in experimental trials if the analytical results are not to be so variable as to risk the whole project being a waste of time for all concerned.

Whilst every endeavour is made to keep contamination of human foodstuffs to a minimum, attention needs sometimes to be directed to the fate of accumulations of insecticide which are left when a product has been removed from its storage place or processed. For example, when maize on the cob or sorghum on the head is insecticidally dusted in native household or village storage containers, the loose dust will gradually seep to the bottom. When the container is emptied this dust, with some buried grains, may be thrown out and the heavily contaminated grain eaten by poultry. The likelihood of taint of flesh or eggs is very small but must be borne in mind. A more likely risk of such taint could arise from steady feeding, *e.g.*, of BHC or lindane-treated grain over a number of weeks. The limit of lindane for continuous feeding, if taint of eggs is to be avoided, probably falls between 1 and 5 p.p.m. in the total diet (Black, Getty *et al.*, 1950; Milne, 1953). Similarly, attention must be given to the use of winnowings and trash from dusted grain—which may contain bran, broken grains, and a relatively high amount of insecticide—to ensure adequate dilution with untreated products before feeding to poultry, pigs, cattle, etc.

The extent to which dust seeps through a treated heap can be markedly reduced by selecting one with good power of adhesion. Laboratory tests with eleven commercial samples of lindane dusts showed that, during a standard sieving procedure, the amounts adhering to groundnuts in shell ranged from 0·14 to 0·45 per cent. by weight (Green, 1960).

In the experimental treatment of certain commodities, like tobacco and cocoa, the risk of taint is of great concern to the trade and special precautions are necessary to avoid it. Indeed, the restrictions imposed by industry may sometimes so limit the acceptable insecticidal treatments as to leave little prospect of success. It is perhaps not inappropriate to mention here insect infestation as a form of biological taint. It is rare that an experiment will give complete and scientifically acceptable results without the inclusion of an untreated control, and Government authorities and commercial organisations are often persuaded only with difficulty to make available even a small quantity of produce which is to remain untreated and to become infested when they feel that another part of a parcel is to be treated and therefore will suffer less damage. If a suitable control cannot be run it is as well to ponder the wisdom of undertaking the remainder of the test.

Fumigation is rightly considered a method of treatment to be applied only by trained staff able to anticipate how gases will behave under the conditions of application. In contrast, the belief seems widespread that any unskilled operator can be given almost any kind of applicator and left to apply an efficient treatment with a contact insecticide. We would therefore like to conclude by emphasizing that there are so many variables and sources of error in the choice and application of such treatments as to render the subject one of even greater complexity than fumigation, although normally, without the same risk to life. One sad realisation of long experience is the rarity with which anyone who carries out experimental or practical field-scale control of stored-product insects with contact insecticides suspects the efficiency of the application as an important contributory cause of poor results.

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Discussion

Dr. J. Rawnsley referred to Dr. Freeman's remarks on the disinfestation of ships, and mentioned the difficulties sometimes experienced in dealing with the problem diplomatically. In Ghana 75,000 tons of cocoa had been disinfested in the current season, and still the ship owners were maintaining that infested cargoes disclosed at unloading were the result of poor fumigation in Ghana. Dr. Freeman considered that probably the best approach to such a problem was the introduction of suitable legislation requiring ships to be certified as free from infestation, or that the containers should be considered as part of the produce.

In reply to a further remark by Dr. Rawnsley, to the effect that he had expected more mention of malathion in Dr. Parkin's paper, Dr. Parkin said that there was little doubt that malathion was going to be of value in the stored-products field. It had shown itself to be especially effective against *Oryzaephilus* and *Tribolium*, and had a low mammalian toxicity.

Mr. L. A. W. Hayward referred to an apparent contradiction in Dr. Parkin's remarks, for he had stated in his paper that *Tribolium* was not well controlled by malathion. In Nigeria, malathion had proved singularly successful, although he realised that the conditions were different. Mr. A. A. Green elaborated Dr. Parkin's remarks, and showed that the effectiveness of malathion depended upon the dosage. Used with small bags, it was successful: used with large bags, it was less successful. This should not be considered as a failure of malathion, but as an indication that the vapour effect of the material was more efficient under the conditions of one type of experimental layout than of another.

Mr. J. Forsyth reported that there had been two cases in Ghana of eggs tainted, reputedly from the feeding of lindane-treated maize to poultry. Dr. E. E. Turtle was able to confirm, as a result of tests carried out in the United Kingdom some years ago, that tainting of eggs readily occurred when fowls were fed with BHC-treated grain.

Mr. T. Greaves enquired of Dr. Freeman whether the unusually hot summer experienced in the United Kingdom in 1959 was responsible for the heavy infestation of *Oryzaephilus surinamensis* (L.). Dr. Freeman thought that the weather was one of the factors, particularly in June, but *Oryzaephilus* populations had been building up for some time, and more farmers were nowadays storing in bulk, so that it was not a clear-cut association with the summer's weather.

The discussion ended by Mr. L. Lefkovitch asking whether there was any likelihood of the various Commonwealth territories setting up organisations of the type described by Dr. Hall, to which Dr. Hall replied that some countries had already made a start. Ghana, starting with the cocoa problem, had extended its organisation to some extent, Jamaica had recently established a unit, and a trained officer with a staff was dealing with infestation problems in Central Africa, so that within the past five years it could be said that some progress had been made.

DISCUSSION ON THE BIOLOGICAL CONTROL OF INSECTS AND WEEDS

Chairman: Dr. W. Cottier, *Director, Entomology Division, D.S.I.R., New Zealand*

The Chairman said that Mr. Frank Wilson, who would be addressing them, was well equipped to deal with the subject, as he had worked for twenty years on the biological control of insects and weeds. As only one paper was being presented, there should be ample opportunity for discussion, and he hoped that his hearers would take full advantage of it.

The Future of Biological Control

By Mr. Frank Wilson

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I have entitled this address " The Future of Biological Control " so that I can give particular attention to the probable developments in this field during the coming period.

Biological control tends to have strong supporters and vehement detractors, and to pass through alternate phases of popularity and denigration. After the war it passed through a period of disparagement resulting partly from its own inadequacies but more from the high hopes raised by DDT and the subsequent potent chemical insecticides. This loss of esteem was expressed by Taylor (1955), whose criticisms were the more forceful coming from one who had participated in such a notable biological control success. Taylor's paper has been referred to by Clausen (1958) and others, and has been replied to in detail by Simmonds (1956). However, there are many signs that biological control is again swinging into favour. The reason lies partly in the disillusionment that has followed the great expectations raised by chemical control, partly by the growth of interest in population dynamics, and partly by developments in biological control itself.

It is no new story that the blessings of chemical control are not unmixed. This is indeed one of the most frequent themes in current entomological writing. Entomologists and farmers have long been resigned to the knowledge that chemical control is expensive, transitory, and recurrent, but to these defects must be added in particular instances the following: increase of a pest other than that against which the chemical is being used; increase of the pest itself; the conversion of innocuous species into pests; the destruction of pollinators; damage to man, animals, and plants; the development of resistant strains of pests; and the build-up of toxic residues in the soil.

These matters have been discussed by many workers including Solomon (1953) and Hinton (1955). Solomon has commented that over-emphasis on chemical control has retarded the development of the study of control from an ecological point of view, and has employed a large fraction of the total human and material resources available for investigation into the control of pests.

The fact that chemical control tends to magnify the problems it copes with and to create fresh problems in the process has convinced many entomologists of the need to base pest control so far as possible upon natural controls, and to employ chemical controls in such a manner that they supplement rather than replace these natural controls. Unfortunately, insecticides are generally antagonistic to biological control. If natural enemies provide some measure of control but insecticides cannot be dispensed with entirely, the insecticides used commonly reduce the effectiveness of the natural enemies. There is growing awareness of the need to resolve this incompatibility, and it is only by doing so that biological factors in control can be brought to maximum effectiveness and chemical schedules minimized.

The harmful characteristics of chemical insecticides are in no sense surprising, for predominantly insecticides are developed for, and tested by, their capacity to kill pests of one kind or another. The innumerable side effects are far from adequately tested. Insecticides tend therefore to be promoted on the basis of their virtues, but their defects become apparent only slowly. Chemical insecticides will undoubtedly continue to predominate in pest control for many years to come, but we are entitled to urge the chemical companies themselves, as well as entomologists and farmers, to pay increased attention to the complex ramifications of the insecticidal applications.

Population theories have had very little effect on the practice of biological control in the narrow sense. Much work of importance has been undertaken and developed to the point of considerable economic significance without the procedures being influenced to any important degree by the theoretical conflicts of population dynamics. We may expect that much biological control work during the next ten to twenty years will remain similarly uninfluenced, for the worker in this field is dealing with problems of extreme complexity, and carrying out field experiments involving an enormous number of unknowns. Biological control investigations are undertaken primarily for practical purposes, and Governments provide severely limited staffs and facilities with the aim of finding solutions to pest problems. Despite the complexities of biological control work, it is not unusual for an investigation, whether it has been successful or not, to be terminated in a few years, and for the entomologist concerned to have several problems for concurrent investigation. This attitude of authorities is in urgent need of revision, and reflects the inadequate provision made for biological control research in an era dominated by chemical control. Biological control problems frequently require protracted investigation. In this connection, it is interesting to note that the attempt at the control of prickly pear in Australia, which proved so successful by about 1930, had been initiated at the beginning of the century, and was resumed twice before success was attained (Wilson, 1960); also that work on red scale in California extended over fifty years before the introduction of *Aphytis lingnanensis* (Comp.) from South China in 1949 gave an appreciable degree of biological control in a limited coastal area (Clausen, 1958).

Though population dynamics has had little effect on biological control in the narrow sense, it has created a new climate of opinion in regard to it. It is perhaps A. J. Nicholson above all who has inspired the modern approach to problems of pest abundance. When Nicholson (1940) questioned whether a spray which gives an excellent kill of a pest will give equally excellent ultimate results when the spray is applied in the same area for a number of years, and argued that the density of the pest might be unchanged or even higher irrespective of adverse effects on natural enemies or the development of resistance to the insecticide, he raised matters of critical importance. His remarks formed the basic thesis on which workers in Nova Scotia developed spray schedules that harmonize the biological and chemical control of apple pests. These schedules employ pesticides that are relatively innocuous to natural enemies, and reduce insecticidal sprays to the minimum required for immediate control of specific pests (Pickett *et al.*, 1958).

The biocoenotic and ecological approach to pest problems is being followed increasingly in many parts of the world, not least in England where Massee (1958) and his co-workers have for many years been studying the complex arthropod environment of orchards and shown the great changes that insecticides produce in the species structure. The modern approach to a combination of biological and chemical control is seen in the use of both against citrus pests in California.

Developments in population theory therefore are creating a climate of opinion in which increasing importance is being attached to biotic elements in control. These and chemical means of control are seen as two of the many interacting factors in the ecology of a pest which can be manipulated in order to bring pest populations to a level more conformable to human interests. From this point of view we may expect that in the future biological control, like chemical control, will increasingly come to be regarded as a particular aspect of the comprehensive investigation of the total ecology of pests.

It should be noted in passing, that biological control investigation has proved a stimulating source of ideas bearing on population dynamics, and animal and plant ecology. In the coming period we can expect this to continue, and population dynamics may profit more in the short term from the ideas and stimulus provided by contact with the field problems of biological control than biological control will benefit from the theorizing of population dynamics. Ultimately, however, when the basic groundwork of population theory is adequately laid and broadly agreed upon, we may expect it to determine to a greater extent than at present the aspects of biological control investigation to which the research worker devotes his attention.

The growth of interest in biocoenotics tends to obscure the fact that biological control is predominantly concerned with alien pests. In Australia, for example, our crop plants are virtually all introduced species, and many of our insect pests and most of our weeds are alien. In such an area there is great need and scope for biological control research, and despite efficient quarantine new pests continue from time to time to become established. It is frequent for species established in new countries to be more serious pests than they are in their indigenous area. Such introduced species are seldom accompanied by important natural enemies and, as this is an apparent explanation of their increased importance, it is commonsense to do something about rectifying the position. However, the rate at which natural enemies of pests are introduced into new countries such as Australia is very slow by comparison with the number of pests requiring attention and the large number of natural enemies that could be introduced.

The question arises whether the prospects of success are sufficient to justify the great amount of work involved. Without agreeing with Taylor's pessimistic conclusions, it must be accepted that the prospects in any individual instance are not particularly bright. Biological control is sometimes described as an art rather than a science, by which it is implied apparently that it is a hit-or-miss occupation—though this is a view of art with which Leonardo da Vinci would scarcely have concurred.

I have recently had occasion (Wilson, 1960) to review Australian work on the biological control of insects and weeds, and that review indicated that a relatively high degree of control was obtained against eight insect pests and a lower degree of control against another twelve. Against the weeds, a high level of control was obtained with prickly pear and partial control with St. John's wort. Though admittedly their evaluation is a very difficult matter, these results are far from negligible, and well justify the overall scientific effort made. Also, it must be remembered that none of these problems was fully investigated, and though the investigations were sometimes protracted and thorough, they were more often empirical and brief.

It is customary to characterize attempts at biological control as " successful " or " unsuccessful," according to whether or not a species ceases to be a pest after the introduction of natural enemies. In reality, many different degrees of control are obtained, and while one seeks, and may occasionally secure, perfect biological control, one more frequently obtains a lesser degree of control which may yet be of distinct economic value. Biological control at this lower level of effectiveness may reduce the loss and trouble caused by pests, and to the extent that it does so is successful and a useful contribution to agriculture. There tends in fact to be a double standard in judging insecticidal and biological control, standards of perfection being applied only to the latter. This is no doubt a tribute to the extremely high level of control that has sometimes been attained—usually on certain oceanic islands.

There has been a good deal of discussion of the effectiveness of biological control in islands and in continental areas, but an important point seems often to escape attention. It is no disparagement of the remarkable successes obtained in some islands to point out that similar control over an equal area on a large continental mass would usually be regarded as a partial success of little value.

It is unrealistic, in my view, to expect a single species of natural enemy to provide adequate control of its host over the whole area that the pest occupies in a continent. For example, in Australia, *Cactoblastis cactorum* (Berg.) is markedly less effective in the control of *Opuntia inermis* in the cooler areas occupied by this plant. Similarly, *Microphanurus basalis* (Woll.) gives a valuable level of control of *Nezara viridula* (L.) over much of mainland Australia, but is quite ineffective in the inland parts of New South Wales. Our attempts to improve the overall biological control of *N. viridula* have been directed chiefly to obtaining strains of *M. basalis* or other parasites from the cooler areas of the world in which *N. viridula* is indigenous.

It is readily appreciated, of course, that tropical islands often provide conditions in which host plant, pest, and natural enemy can all develop continuously. Under these conditions there is no interruption in contact between host and natural enemy, such as normally occurs in winter in colder areas, which is the evident reason for the common tendency for host populations to forge ahead of their natural enemies in the spring or early summer in these cooler areas. This temporary loss of contact is probably of great importance, and Varley (1959) has suggested that the sequence of sowing, growing, cropping and ploughing may present pests with a special opportunity for increase by hindering their natural enemies.

One of the great needs in biological control is to be able to define the necessary characteristics of a natural enemy required to control a given pest in a given area, and to measure against this requirement the characteristics of the natural enemies available in nature for this purpose. At present this can be done only very crudely, but increased precision in defining requirements would make practical results more frequent. It is strange to reflect that although there are so many examples of successful biological control in the world, we cannot give an adequate account of why these particular examples were successful. Surely there is very much to be learned from close study of these particular pests and their natural enemies which should help us to define the required characteristics. I would suggest that universities sited in the vicinity of outstanding examples of biological control should take the opportunity to undertake long-term investigations in this important field.

This matter has a bearing on the general question of the development in the laboratory of new races or strains of natural enemies adapted for specific climatic or other conditions. DeBach (1958) has pointed out that parasites usually exhibit a narrow range of adaptation to environmental conditions, including poor climatic tolerance, lack of synchronization between host and parasite biologies, failure to recognise the host environment, and inability to survive on certain host plants. Wilkes (1942, 1947) has shown that by selection various characteristics of laboratory stocks of *Dahlbominus fuscipennis* (Zett.) (preferred temperatures, proportion of sterile females, mean fecundity, etc.) could be changed. Other workers (*e.g.*, F. J. Simmonds) have produced similar results. It is evident that strains of natural enemies which differ in important characteristics commonly occur and can be used to produce, by laboratory selection, strains with required characteristics. Work on these lines is in progress in Canada, California, and elsewhere, and promises to produce results of considerable interest.

There seem to me to be two difficulties which restrict at present the practical value of these selection procedures. The first is adequate definition of the qualities required. The second is that deliberate selection for required characteristics is likely to be accompanied by involuntary selection for associated characteristics which could be disadvantageous in nature. Allen (1958) has commented that genetic differences exist in a species which fit segments of the general population to particular ecological environments. Such genetic differences may be found at the same time in different places, or in the same place at different seasons. From the viewpoint of biological control, the main need appears to be to establish in the area where control is desired the maximum variability in the genetic material of the parasite concerned. From this rich genetic pool, natural selection would choose the gene combination appropriate to each environment. Successful laboratory selection of strains adapted to particular environments seems to require more precise knowledge of the total strain characteristics required than we are likely for some time to possess.

Effective biological control requires capacities in a natural enemy which are very difficult to define or measure but easy to test by release in the area in which it is required to control its host. It may be somewhat less difficult to define adequately the relevant ecological characteristics of the area in which the natural enemy is to be released, and to ensure that some at least of the imported material of a natural enemy is that which has been subjected to natural selection in an area of similar characteristics. The inability to forecast accurately whether a natural enemy can be established in a given area, or whether it will prove effective if established, has—unwisely in my opinion—tended to minimize for many biological control workers the importance of giving special study to the natural enemies in those parts of the area where the pest is indigenous which are analogous in climate and other ecological characteristics to the area in which biological control is desired. Biological control, in fact, seems to be in need of a concept which we may call the " ecological analogue." Areas (usually in the indigenous and newly invaded areas occupied by a pest) would be ecological analogues for a given species (whether host or natural enemy) if they were similar in respect of all the ecological factors of significance for the species. When such ecological analogues can be adequately defined, we may expect the selection of natural enemies for biological control purposes to be on a sounder scientific footing than it is at present, and the foundation would also be laid for the laboratory selection of strains suitable for particular localities.

It is, of course, clear that, although the specific labels applied to natural enemies are useful, they can be highly misleading if taken to indicate the basic units involved in biological control. As is now well known, different strains of a species may attack different hosts, or have different environmental requirements, or differ in other important respects. The specific label is probably no more precise when applied to host insects.

Of the difficulties that beset the biological control worker none is more frustrating than inability to demonstrate the effect of the introduction of natural enemies upon the abundance of their hosts. When biological control is highly successful its success is accepted generally on a basis of commonsense without strict proof of causal relationship. Lower degrees of control tend to be disputed or disparaged and, oddly enough, denials that biological control has been effective in particular instances are usually made more confidently than assertions to the contrary, though both suffer equally from absence of scientific proof. The reduction in host abundance caused by lower degrees of biological control tend to be attributed to weather unfavourable to the pest, improved insecticidal practices, or to other factors, and in time the lower level of abundance comes to be accepted as normal, without significance being given to the part played by the natural enemies.

Ultimately, as Smith and DeBach (1942) have suggested, methods of collecting and analyzing field data may be developed by which it will be possible to measure the effect of a natural enemy on the abundance of its host without maintaining separate plots with and without the presence of the natural enemy. In the absence of such techniques, which may eventually be produced by developments in population dynamics, the Californians have made notable contributions to demonstrating the effect of natural enemies on host abundance, by developing sleeve, insecticidal, biological, and manual check techniques.

Incidentally, Clausen (1954) has said that the exact assessment of the result of the introduction of a natural enemy is very much more difficult than that of an application of insecticide. This is, of course, true if one considers the sole effect to be the percentage kill of the pest against which the insecticide is directed. To evaluate all the other effects—which are not measured—upon the general population levels of the pest and the other Arthropods in the environment would scarcely be simpler in many instances than an assessment of the effect of a natural enemy.

Another major development in biological control has been the employment of diseases for the control of pests. The results obtained against *Colias philodice eurytheme* Boisd., the alfalfa butterfly, in California, *Gilpinia hercyniae* (Htg.), the European sawfly, in Canada, and against cabbage pests in a number of countries, are sufficiently important to make an extension of work with insect diseases, especially viruses and bacteria, inevitable. Microbial control has a number of advantages. Micro-organisms can sometimes be cultured at a lower cost than can other natural enemies; the cost of application as a spray or dust is comparable with that of an insecticide; generally micro-organisms are harmless to man and plants; and they are not affected by most insecticides. However, as Clausen (1956) has pointed out, there has as yet been no demonstration of microbial control comparable in completeness and permanence to that of the cottony cushion scale by *Rodolia cardinalis* (Muls.). He comments that under certain circumstances the pathogenic organism may have an adverse effect on the parasites and predators of the pest, and that the net effect may be detrimental. Bucher (1958) has also adopted a cautious view of the value of insect diseases. Though the dissemination of diseases by man has controlled a few insects, many other attempts have failed and there are definite limitations to the method. Bucher refers to the lack of mechanism for dispersal in micro-organisms, their susceptibility to climatic factors, and other limitations.

My own opinion is that insect disease constitutes a most promising development in biological control. The example of the European sawfly suggests that where a high level of control is not essential the introduction of a disease may of itself contribute substantially towards adequate control. The more interesting part of disease work, however, seems to lie in the use of disease sprays and dusts which can be applied in the same way as insecticides. The possibilities are of great interest because diseases in general appear to be sufficiently specific for the natural enemies of pests to be immune from the diseases to which their hosts are subject. Disease applications therefore have the great advantage over insecticides that they are not likely to create the same serious side effects. There does therefore appear to be ground for hope that diseases may play an important part in pest control, and may make an important contribution to a solution of the serious problem of the incompatibility of insecticidal controls and natural enemies. The question of host specificity of insect diseases is particularly important, especially so far as the susceptibility of beneficial species is concerned. For example, in Australia, the use of *Bacillus thuringiensis* against cabbage pests has been opposed on the ground of its possible adverse effect on *Cactoblastis cactorum*.

There is a marked tendency in discussing biological control to give far more attention to insect than to weed pests. This reflects the greater effort that has been directed towards insect control, but there is no reason for believing that biological control is likely to be less effective against plants than animals. There has in fact in recent years been a great growth of interest in the biological control of weeds, especially since work on St. John's wort spread from Australia to U.S.A., Canada, New Zealand, and recently to South Africa. There is now rather general recognition that organisms living at the expense of weeds can play a very important part in determining their abundance.

It has been argued that weeds indicate bad farming, and that biological control is undesirable as it tends to inhibit good practices (such as pasture improvement) which would themselves deal with the problem. Though there is an element of truth in this, it is far from satisfactory as a general criticism. It would, for example, be a difficult argument to present to the farmers who were once afflicted with 60 million acres of prickly pear in Australia.

Also, it is clear that it does not apply to weeds which are normally controlled by chemical or mechanical means, and pasture improvement may not in itself be practicable on particular terrains. Often enough, the farmer's resources or the prevailing economic conditions do not permit the improvements to be undertaken. It is more realistic to consider the biological control of a weed as tending to free the farmer to utilize land in a manner most suited to his requirements rather than in a manner determined in part by the weed.

There can be little doubt that attempts at the biological control of alien weeds will be made with increasing frequency in the coming period, and the successes already attained lead to the expectation that a sufficient proportion of successful results will be obtained to justify a marked extension of activity in this field.

Another matter of general importance is collaboration in biological control. Such investigations are essentially of an international character, and the worker in this field is very dependent on the co-operation of institutions in other countries. We have long had the advantage of the fine service provided by the Commonwealth Institute of Biological Control, which has developed from an offshoot of the Commonwealth Institute of Entomology into a vigorous and growing independent body. The Americans have long had their own well-known organizations. In 1955, Western Europe formed the Commission Internationale de Lutte Biologique, and in 1958 the foundations were laid in Prague for a similar organization to serve the Soviet bloc.

My personal opinion is that ultimately, the special need for collaboration in this field must lead to the formation of a world centre to serve the needs of national biological control institutions. Individual countries would gain much from a central organization which had the resources to disseminate information, despatch required natural enemies, organize collaborative investigations, and possibly maintain stocks of parasites, predators, and diseases, act as a centre for appropriate taxonomy, and publish papers. The existence of strong regional organizations in the British Commonwealth, the United States, Western Europe, and the Soviet bloc should make the ultimate formation of such a world organization much simpler than it would otherwise be.

Meanwhile, we should encourage all attempts at collaboration and joint enterprises, such as the Hawaiian-Australian lantana investigation, and the proposal by the Commonwealth Institute of Biological Control to undertake work on particular problems (such as codling moth and potato tuber moth) on behalf of the many interested countries, and we should foster the exchange of material and information between the existing regional organizations.

It is remarkable how little we know of the natural enemies and diseases of many common pest species. Even with red scale, which has received so much attention from the Californians, there is far from adequate knowledge. Such investigations need to be prosecuted on a global basis, and to do this effectively requires the collaboration of institutions in many countries. Such broad-based scientific work might be far more productive than isolated, unco-ordinated investigation by a number of countries working independently.

I have sometimes wondered whether a single pest species of great general interest should not be singled out for intensive research by scientists in many countries working according to a co-ordinated programme. The objective would be a world study of the selected species, aiming particularly at knowledge of its biocoenotics, and general ecology: and at the best means of manipulating its abundance. Thorough study of the species' natural enemies would figure prominently in the programme. Such a concentrated study might lead to a considerable advance not only in our knowledge of the species selected, but also in our understanding of the basic problems involved in regulating insect numbers in accordance with human interests.

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Discussion

The Chairman, opening the discussion, suggested that many of those present held opinions on biological control that others would consider idealistic, but such feelings should not prevent anyone from saying what was in his mind.

In direct response to that invitation, Dr. H. R. Lillie pleaded against the wholesale use of agricultural chemicals, and expressed the hope that the world at large might realise that Nature could not be conquered. This led to an immediate rejoinder from Mr. D. J. Colwill, who exemplified the value of insecticidal chemicals in reducing the death rate from malaria by one-third between 1943 and 1948, and who also pointed out the value of chemicals in providing sudden checks under circumstances where methods of biological control would work too slowly to be of benefit to a particular crop. Mr. Wilson said that he agreed in principle with Dr. Lillie's remarks, and that a similar view had received approval at the recent International Conference for the Preservation of Nature held in Warsaw where much concern had been expressed on the side-effects of the use of agricultural chemicals. The most important aspect of biological control lay in its contribution to ecology, and the effectiveness of changes in the ecological environment of mosquitos, such as those brought about by the draining of swamps, were too well-known to require further comment. He would therefore urge an increase in the basic ecological approach, as opposed to the use of chemical " fly-swat " methods which killed without understanding the insect, and suggested that, for over-all results, it was probably better to have a slight degree of infestation without the use of chemicals than no infestation *and* chemicals.

Dr. K. Mellaney drew attention to the differences between the requirements of control in the fields of agriculture and medicine. In medicine, all the pests and vectors had to be eliminated, for man was unable to compensate for the depredations of even a low-level infestation. In agriculture, on the other hand, there could be tolerated levels of infestation, especially in countries like the United Kingdom where crop preferences had been long established. He suggested that there were three levels of attack. In the first, the pest was present all the time and probably caused little damage, such as the 10 per cent. of wheat plants infested by the wheat bulb fly which compensate for the attack by extra tillering; the second level was where the damage was of such a nature as to be not particularly costly to the grower and therefore not worth controlling; and the third level was that of the devastating attack that could only be controlled by the use of chemicals. If, he said, these levels could be recognised, then biological control methods would be of value in keeping populations of pest insects to the lower levels, but it could not be relied upon at the third level, which represented an epidemic. He repeated that, as every human life was valuable, 100 per cent. protection was then required and so biological methods had little place in medicine.

Dr. A. P. Arnason thought that biological control measures were unlikely to provide wholly effective plant protection without the assistance of chemicals, and gave the example of apple in Canada which, without sprays to control scab and *Cydia pomonella* (L.) would produce fruit so blemished as to be unsaleable. He was not in favour of the indiscriminate use of insecticides, and agreed with Mr. Wilson that natural control agents could and should be used with chemicals. In some crops more than others the grower would have to depend more on the use of chemicals than on biological methods to increase yield and quality for many years to come. **Mr. Wilson** pointed out that Dr. Pickett and others in Canada had shown the value of biological control in permitting a reduction of the spray programme for apples. Dr. Arnason said that this work had been carried out by using selective chemicals having minimal effects on natural enemies, and that in other parts of Canada it had not been possible to go as far as the workers in Nova Scotia.

Mr. J. R. Metcalfe stressed the importance of avoiding the hit or miss method of biological control. It was no uncommon story to learn that insects were introduced into an area, and just as they were about to produce the results originally expected of them the project was shelved as being of little value. As an example, he cited *Lixophaga* used in the control of *Diatraea saccharalis* (F.) on sugar-cane in the West Indies. It was successful when introduced from Cuba to St. Kitts in about 1928, but took ten years to become effective in Antigua, and was so difficult to establish in Barbados that it was collected from its entire natural range, bred and cross-bred between strains, and was now proving sufficiently encouraging to suggest that attempts be continued for a further few years with the Barbados strain.

Mr. D. V. Murthy said that the release of a suitable parasite did not always provide a permanent panacea, and that even when one gave successful results it sometimes required to be re-introduced periodically into the territory, just as chemical sprays required to be repeated; and further, that the release of parasites or predators should be attempted in an area even if on an earlier occasion they did not prove successful. He wondered whether Mr. Wilson would advise using a parasite or a chemical when both were available and suitable for the control of a given pest. As an example of the limitations of biological control, he cited the case of the sugar-cane weed " striga " on which he and his colleagues had been working. A Curculionid [*Smicronyx albovariegatus*] and a Nymphalid [*Precis orithya swinhoeii*] were found to give good but not total control, and were useful in keeping the weed down, but herbicides were necessary to eradicate it.

Mr. Wilson said that these were problems encountered in many countries. He readily admitted the limitations of biological control, and said that it was common to obtain partial control so that chemicals were still needed for eradication. The converse was also true to some extent, for in Australia the citrus red scale is usually controlled by chemicals, but in some areas at some times a parasite introduced by Compère in 1906 still gave a useful measure of control. The effects of chemicals on natural enemies required most consideration in regions where a pest was under partial or fluctuating control by its natural enemies. The cabbage aphid was a general pest on cruciferous crops in Australia and it was the practice to spray against it every 2–3 weeks, yet in some places spraying was discouraged or prevented because the degree of biological control there achieved was sufficient to control the pest even where growers would have sprayed because the populations built up to serious proportions before the effects of the natural enemies were fully noticed. Again, spraying against such Lepidoptera as *Plutella* resulted in severe aphid increases, so that further sprays had to be applied. These examples served to underline the importance of studying the factors to be considered when biological and chemical methods were used conjointly.

Mr. D. J. Colwill asked if there was any information on the biological control of the weaver bird [*Quelea* spp.] in Africa. **Dr. F. J. Simmonds** agreed that *Quelea* posed a difficult problem that was worthy of investigation from the point of view of introducing predators or diseases, but their possibilities were entirely unknown and as the African predator complex was already fairly broad the introduction of effective alien species would probably be far from easy.

Dr. Simmonds ended the discussion by referring to Mr. Metcalfe's remarks on the need to pursue biological control measures for a considerable period. It was his experience that the reluctance to persist was not on the part of entomologists, but was due to the financial strictures of the authorities employing them when good results did not occur at once.

DISCUSSION ON INSECT ATTACK IN RELATION TO THE PHYSICAL CHARACTERS AND PHYSIOLOGICAL STATE OF THE PLANT

Chairman: Prof. O. W. Richards, *Imperial College of Science and Technology*

The Chairman opened the meeting by referring to the fact that many entomologists divorced their thoughts from those of the botanist, whereas in fact it was often necessary to consider both aspects in relation to a given problem, for plants formed the main substrate of the majority of insects. The two speakers would be considering the subject from somewhat different viewpoints.

Resistance of Host Varieties to the Wheat Stem Sawfly, *Cephus cinctus* Nort. (Hymenoptera: Cephidae)*

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The wheat stem sawfly, *Cephus cinctus* Nort., is a native of Western North America where it originally lived in grasses. It has, however, caused economic damage in wheat in the Great Plains Area, where losses of twenty million dollars per year have occurred.

Plant breeders, in conjunction with entomologists, in 1946 produced Rescue, a solid-stemmed resistant spring wheat. This variety, as well as Chinook, which was produced in 1952, greatly reduced sawfly losses. Both varieties were produced from crosses between high quality spring wheats and low quality solid-stemmed wheats that originated in Spain and Portugal.

It has been found that the resistance of these varieties as well as that of Golden Ball, a solid-stemmed durum wheat, varied considerably when grown in different environments. Hence a study was initiated, in the light of earlier work, to determine the causes of the variation, with the object of overcoming or at least of reducing it.

The adults of the wheat stem sawfly emerge in mid-June and fly for about two weeks. Each female will deposit one egg inside forty different stems; many will infest the same stem. Selection of the stem and of the oviposition sites within that stem are determined by its stage of development. Most females oviposit in the uppermost two internodes that are elongating at the time of oviposition. Hence, as the stem grows, the eggs are laid in progressively higher internodes and the oviposition sites within each internode also change. As the internode elongates and matures it hardens first in the upper portion and forces the female to oviposit lower down the internode where her ovipositor can penetrate the softer stem tissues. However, before many eggs are laid lower down the internode, the next internode above has started to elongate and will attract the females to it. Hence, most of the eggs are laid in the upper part of each internode (Holmes and Peterson, 1960).

The eggs hatch in about five days and the larvae feed on the inside of the stem wall. When the stem becomes ripe, the larva moves down cutting the stem off at ground level, and overwintering underground in the base of it.

The larvae pass through five instars in Marquis wheat and a variable number in other hosts (Farstad, 1940), ingesting both parenchyma and vascular tissues (Holmes, 1954) thereby causing a reduction in yield to their hosts (Seamans, *et al.*, 1945). When the moisture contents of the host stems fall below 50 per cent. the larvae start cutting the stems at ground level (Farstad, 1940). Larval survival is reduced by premature ripening of the host stems, which results from drought, and by rank, late plant growth, caused by excess moisture during the growing season (Criddle, 1915, 1921; Seamans, 1945; Platt and Farstad, 1946). The sawfly is best suited for areas where the annual precipitation is between ten and twenty inches; it has never been a problem in irrigated wheat.

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* This is essentially a summary of two papers that will be published in " The Canadian Entomologist."

Farstad (1940) was the first to relate sawfly resistance to stem solidness. He believed that the amount and consistency of the pith in the lumen of the stem directly influenced larval survival. Although there were differences in sawfly survival among hollow-stemmed hosts, only solid-stemmed wheat varieties possessed adequate levels of sawfly resistance (Platt and Farstad, 1946). Because reduced light intensity reduces stem solidness, the loss of resistance of solid-stemmed hosts is attributed to cloudy weather during the early part of the summer (Farstad, 1940; Platt, 1941; Platt and Farstad, 1946; Holmes, *et al.*, 1960). Roberts (1954), however, concluded that stem solidness was not related to resistance to sawfly larvae, but rather that resistance to larvae depended on the stage of host development at the time of infestation.

Egg and larval mortalities should be considered separately because the eggs require only moisture, while the larvae must obtain their nutrients from their hosts and be able also to move down to the base of the ripening stems so that they can overwinter underground. Within a stem the larvae destroy each other as well as the unhatched eggs; only one can survive. When high densities of sawflies occur, mortality from cannibalism is great, particularly in susceptible hosts.

The so-called solid stemmed wheats normally contain hollow portions. Comparisons of the hatching of sawfly eggs in these portions with that in the portions completely filled with pith showed that significantly higher egg mortality occurred in the solid parts of the stem; they hatched as well in the hollow regions of the resistant hosts as in the hollow-stemmed susceptible hosts. The resistance of the pith to the eggs, however, varied between internodes of the same stem and between stems of plants grown under different environmental conditions. It is suggested, therefore, that egg mortality may be caused either by excess moisture or by mechanical damage caused by the pressure of the pith on the eggs.

Similar comparisons between the solid and hollow parts of the same stems show that early larval mortality is significantly increased by stem solidness, comparisons between stems with different amounts of solidness show that later larval mortality is also increased by increased amounts of stem solidness.

Resistant varieties, then, depend on stem solidness for their resistance to the larvae. As in the case of resistance to egg development, the effectiveness of the pith on larval mortality varies between the internodes of the same stems apparently as a result of the environment. The mortalities of eggs and first-instar larvae in the pith vary independently and hence are apparently caused by different factors.

The major difference in sawfly survival in resistant and susceptible hosts occurs during the later stages of larval development. In all hosts a major drop in the numbers of surviving sawflies occurs early in the growing season; the main cause is cannibalism in susceptible hosts and resistance in resistant hosts. This is followed by a gradual decline, which is succeeded by a second major drop in survival in the resistant but not in the susceptible hosts. It is this last drop that differentiates the resistant from the susceptible hosts. Resistance to larvae particularly in the later instars is much more important than resistance to eggs in all the resistant varieties tested.

Larvae from eggs laid in the upper internodes of resistant varieties have better chances of survival than those from the lower internodes. Apparently after they reach a certain size in the hollower regions, they are more able to tunnel through the pith.

Stem solidness, particularly in the lower three internodes, is required for sawfly resistance in both bread and durum wheats. When the environment causes a reduction in stem solidness it also causes a reduction in sawfly resistance. However, Golden Ball, a durum variety, does not necessarily have to lose its solidness to lose its resistance and in this respect it differs from Stewart, another durum wheat. The resistance of Rescue, a resistant bread wheat, and of Golden Ball is generally affected similarly by the same environments. This suggests that the pith of Golden Ball, instead of failing to fill the cavity as is the case with Rescue, may become thinner-walled and hence susceptible. Generally, the pith of Golden Ball is less resistant to larvae than is the pith of Rescue and hence Golden Ball is lower than Rescue in total resistance. In addition, larvae that survive in Golden Ball are larger than those from most other varieties, while those from Rescue are smaller than most.

Major differences in resistance apparently unrelated to stem solidness occur among hosts other than wheat. Minor variations occur in the resistance of hollow-stemmed wheats. Platt and Farstad (1946) reported that Apex and Garnet were extremely susceptible whereas, in most tests, Red Bobs was considerably less so. As the bottom internode of Red Bobs may become solid and partially resistant under certain conditions, it seems that, even in the hollow-stemmed wheats, stem solidness may be a factor in resistance. There is little doubt but that stem solidness is the only major source of sawfly resistance presently available in wheat.

Recently the chemistry of the wheat stem has been studied. Lopatecki, *et al.* (1957) examined the soluble carbohydrates at various stages of development in the stems of sawfly-resistant and susceptible wheats. Kasting, *et al.* (1958) studied the moisture and nitrogen contents. They showed that as the stem matures, its moisture is lost more rapidly in the upper internodes. The downward movement of the sawfly larva in early August is probably a response to the decreasing moisture in the upper internodes. They also showed that the pith of Rescue dries more rapidly than does the stem wall of either Rescue or Thatcher. By mid-August, the stems of Thatcher contained 43 per cent. moisture while the pith of Rescue had fallen to 26 per cent. In early August, many larvae that tunnel down through the pith in Rescue shrink and lose weight before they die. This may result from the desiccation of the larvae as they tunnel through pith that contains insufficient moisture to sustain them. This hypothesis appears to be supported by the observations that drought, resulting in premature drying and ripening of normally susceptible host plants, causes the larvae to be stunted or to die. The pith of Golden Ball, which remains quite moist even in mid-August, is lower than that of Rescue in resistance to sawfly larvae.

There is presently no proof that either a qualitative or quantitative lack of nutrients is a factor in the sawfly resistance of wheats but, as the plants mature, the pith of Rescue loses nitrogen more rapidly than either the stem wall of Rescue or the stem of Thatcher (Kasting, *et al.*, 1958). Golden Ball loses its nitrogen more slowly than either Rescue or Thatcher. The data for both moisture and nitrogen contents of the pith represents the total amounts available to the larvae in that tissue, but the data for the stem wall represent the mean values between the parenchyma and the vascular tissues. Presumably the vascular tissues are richer than the parenchyma in both nitrogen and moisture, particularly as the stem matures. The larvae feed in the vascular tissues in the stem wall and hence may obtain more nitrogen and moisture than indicated by the data for the whole wall. Minor differences in the chemical compositions between stem wall and pith may therefore be very important. This may be of particular importance to the younger larvae.

Roemhild (1954) found a positive correlation between increased thickness of parenchyma cell walls of solid-stemmed wheats and mortality of sawfly larvae. The deposition of lignin during secondary thickening proceeds as the cells mature and hence occurs more slowly in Golden Ball than in Rescue. The resistance of the pith, particularly to the later instars, may be only the result of the mechanical resistance of the parenchyma cell walls. That the pith may be a mechanical barrier is indicated by the frequent failure of larvae to reach ground level in solid-stemmed wheats and their subsequent formation of a cocoon well above ground level. Earlier in the season, larvae often tunnel only part way into the pith, then turn and move back into the hollow regions.

The hypothesis that the pith contains a toxin is appealing but, at present, least tenable. As the sawflies survive well in the cavities of solid-stemmed hosts, the toxin would have to be present in the parenchyma in the pith but not in the parenchyma in the stem wall around the pith cavity, and it must not be transported in toxic amounts in the vascular system. The same arguments, however, could not apply to the hypothesis that a nutritionally lethal imbalance may occur in a larval diet consisting only of pith.

Excess moisture in the pith may be the cause of egg mortality but it is not likely to be the cause of first-instar mortality as this was at least as low in Golden Ball as in the drier Rescue. The pith may be nutritionally unsuitable and/or too difficult to penetrate for many early-instar larvae, but the possible lack of nutrients in the pith appears to be relatively unimportant to the later-instar larvae. The major effect of the pith occurs in August when most larvae are sufficiently mature to require little or no more food. The larvae probably still require moisture and a passage to the bottom of the stem. Consequently the major effect of the pith at this time may be its ability to cause larval desiccation and/or mechanically to impede tunnelling sufficiently to cause death.

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The Water Status of the Host Plant in Relation to Attack by Sucking Insects in the Humid Tropics

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In the field, the main variable factor in the environment to which a plant is exposed is water supply. An amount is required which will permit adequate uptake of mineral nutrients while not retarding oxygen supply to the roots. This means that on soils of widely different textures a corresponding difference in the rate of water supply is needed for optimal vegetative growth. The main results of inadequate water supply to the roots are reduced uptake of nutrients and, in the parts of the plant subjected to the greatest water stress, retarded synthesis of protein (Wiggins and Williams, 1955, p. 345). The main result of inadequate root aeration is abnormal metabolism, in which certain mineral elements become relatively unavailable (Evans and Fennah, 1953, p. 42; Maskell, Evans and Murray, 1953, pp. 59, 60). All metabolic derangements, by one path or another, lead to retarded synthesis of soluble nitrogenous compounds into protein, and to accelerated breakdown of protein.

Rapid population increase of sucking phytophagous insects depends not merely on the rate of reproduction but also on a high degree of larval survival, and the overriding factor in their nutrition is normally the speed at which suitable nitrogenous compounds can be obtained and assimilated. Where such insects are concerned, the requirement appears to be largely restricted to soluble nitrogenous compounds present in the plant before feeding begins. It appears that many members of this group, including well-known agricultural pests, cannot build up large populations by attacking perfectly healthy plants and breaking down the cell protein by the injection of proteolytic salivary enzymes. In some species of Coccoidea which are notorious in the humid tropics for the development of massive populations, and in at least some genera of Thysanoptera, a rapid build-up has been found to occur only in a narrow range of specific circumstances, and to be dependent on the occurrence of appropriate precursive conditions in the host plant (Fennah, 1955, 1959). Such conditions are usually, and perhaps always, suboptimal for plant growth.

To the general statement that metabolic abnormalities predispose the plant to successful invasion by sucking insects, it is necessary in large measure to recognise one exception: this is abnormality caused by a deficiency of nitrogen itself in the plant. Nitrogen-deficient plants are relatively little attacked and in some cases (where the degree of exposure is high and the plant fairly drought-resistant) may be completely ignored. It is of interest in this connection that in parts of Trinidad, W.I., the application of potash to cacao has been negatively correlated with outbreaks of cacao-thrips and mealybugs (McDonald, 1933, p. xi). One of the effects of supplying potash is to depress the level of leaf nitrogen, whether the plant is in sunlight or shade (Maliphant, 1959, p. 77).

The species of sucking insects which often outbreak in massive numbers can be roughly divided, on the basis of where they most commonly settle, into those which primarily attack vascular tissue and those which primarily attack non-vascular tissue. The vascular-tissue feeders have, at best, a choice between a relatively high-pressure flow of protoplasmic sol of low content of soluble nitrogenous compounds near the growing points of the host plant, or a low pressure flow of high content in the senescing tissues. The available evidence clearly suggests that there are limits at both ends, possibly set in one case by over-dilution of the nitrogenous supply and in the other by sluggishness of inflow in the ruptured cells at the apex of the stylets: in both it is apparently the rate of nitrogen intake which becomes unfavourable. The conditions which delimit the activities of different species of sucking insects are unknown, but in some examples the pests develop in a recognisable succession (though sometimes with gaps) which appears to reflect progressive decline in vigour of the host plant, and the later members of the insect succession comprise species which are feeders on senescent tissue, usually vascular, and never on juvenile tissue. For example, in eastern Caribbean conditions, the development of a population of *Coccus viridis* (Green) alone on the youngest leaves of nursery citrus plants is indicative of a chronic but only moderate water stress which is usually associated with a lack of fibrous rootlets and follows a daily rise and fall. The occurrence of this species on some of the hardened foliage, with or without the presence of *Saissetia* on the hardening main stem, indicates a more severe water stress; if, in addition, or subsequently, the diaspine scales *Lepidosaphes gloveri* (Pack.) or *L. beckii* (Newm.) and *Pinnaspis strachani* (Cooley) become common on the lower stems, the host plant is seriously below par. That the occurrence of these insects is determined by precursive conditions in the plant can be inferred from peculiarities of their natural distribution on their host, and from their developmental history after corrective treatment has been given to the host.

The non-vascular tissue feeders are found on leaves and fruit, and their abundance reflects local conditions in the plant. Where such insects are found on the leaf, the conditions with which they are associated may arise from changes in the leaf comitant with age, or arising from local injury. The ageing factor which facilitates infestation is not usually the normal senescence of a healthy plant, but the induced precocious senescence of a retarded plant. The dividing line between leaf tissue that is colonised and that which is ignored may be sharply drawn.

It is not possible to discuss water relations of the plant *in vacuo*, and mention must be made of deficient oxygen supply to the roots, which is usually caused by waterlogging of the soil with stagnant water. An abnormally high water stress is usually developed during the day in plants rooted in waterlogged soil, and, according to the hydrogen-ion concentration of the soil solution, various derangements in metabolism supervene, probably through interference with specific enzyme systems. If the soil solution is acid, iron and manganese may be taken up in toxic quantities, whereas if it is alkaline the uptake of calcium may be promoted and that of potash depressed. Where such conditions are present, the rate of increase of Homoptera or Thysanoptera associated with the plant turns largely on the nitrogen status of the plant and the light intensity to which it is exposed. If both the nitrogen status and the degree of exposure are high, the outbreaks are likely to be severe. The various factors operate on a sliding scale: it was found, for instance, that in the presence of water stress induced by high temperature and low humidity, during daylight hours, and of a moderate or high total nitrogen content in the leaf, the extent of attack by mealybugs on cacao varied according to whether the water supplied to the plants, which were rooted in a neutral loam, was weakly acidified or calciferous, being heaviest where " hard " water was used. Conversely, mealybug attack did not develop on plants of moderate nitrogen status and grown in the presence of much free lime if they were not exposed to dry air and were sparingly watered (Fennah,1959, p. 24).

The regulation of water supply is important where the total content of soluble salts in the soil is abnormally high, or apt to become high during periods of drought. In such conditions a sudden rise in the water table after a long drought may cause severe injury to plants, or even death, from the toxic effects of copious uptake of salts in solution.

Finally, it should be recalled that abundance of water in the soil does not necessarily mean that roots are deprived of oxygen. If the water is well aerated before it enters the soil, and if it moves through the soil rapidly, plant growth is not retarded. As it is the movement of water that is important, local differences in soil texture can lead to marked differences in the growth of plants of the same species or clone occupying such areas. Such differences in drainage and soil aeration vary from year to year according to the intensity and distribution of rainfall, and, if they are large, the plants on one soil type may be markedly more attacked by insects than those on the other. A corollary of this relationship is that in conditions of high temperature and liberal water supply a soil initially with good tilth may rapidly compact, and the water régime appropriate at the outset may correspondingly become excessive as percolation is retarded. Plant growth slows down and insect attack may develop concomitantly.

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Discussion

The discussion was prefaced by the CHAIRMAN remarking that Dr. Holmes had said that the use of resistant varieties of plants provided a better approach than biological control measures in the face of insect attack, but it should be borne in mind that plant resistance was indeed one facet of the environmental aspect which had already been discussed in connection with the broader field of biological control.

MR. E. O. PEARSON asked whether, in breeding for resistance, selection resulting in the wheat variety Rescue had been pursued on the basis of the physical characters of the plant or from observations on the effects of sawfly attack on a wide selection of varieties of wheat exposed to infestation, to which DR. HOLMES replied that selection had been based solely on the criterion of stem-solidness, and that Rescue was the most solid known. MR. W. E. H. HODSON enquired whether the varieties had been developed in Canada or had European varieties also been tried. They had been developed in Canada and Montana, said DR. HOLMES, but Rescue's progenitors came from Portugal.

MR. G. J. KERRICH was interested in the fact stated by Dr. Holmes that a single larvae of *Cephus cinctus* Nort. survived in the stem, out of several eggs laid there, and he wondered whether the adult female was capable of ascertaining that eggs had already been laid in a stem, as was the case with many of the parasitic Hymenoptera. DR. HOLMES thought that the female was not capable of such action, and that she was actuated only by the condition of the plant material; and in reply to a question from MR. M. E. SOLOMON he said that the abundance of the insect appeared to be governed less by the number of stems available to it than by the proximity of the stems to the field margin. Few fields were 100 per cent. infested, and the degree of infestation dropped as the centre of the field was approached.

DR. W. A. L. DAVID, appreciating the relationship between the moisture content of the stem and larval survival mentioned by Dr. Holmes, asked whether an explanation could be given of the fact that stem solidness in Rescue was in itself an unfavourable factor for the survival of larvae. DR. HOLMES was unsure of the reason, but was able to say that its main effect appeared to be that of a mechanical barrier. Larvae became desiccated and lost weight on their migration downwards through the stem to the base of the plant.

DR. HOLMES, in reply to the CHAIRMAN's question on the host range of *C. cinctus*, said that the species was native to a wide range of grasses in western North America.

MR. S. APEJI wondered whether resistance in the different varieties of wheat was, in fact, rather a resistance to oviposition than to egg or larval survival, but DR. HOLMES was able to assure him that there were no differences in the rate of oviposition on the varieties tested.

One of the slides with which Dr. Holmes' paper was illustrated depicted a well-defined margin between attacked and uninfested plants at the edge of a field, and MRS. M. G. MORRIS wondered if the straight line really represented the limit of the attack; DR. HOLMES admitted that it was exceptional, but it was certainly not faked. An enquiry by DR. J. R. T. SHORT referred to the possible relation between *C. cinctus* and *C. pygmaeus* (L.). DR. HOLMES said these might overlap to some extent, but *C. pygmaeus* had not been intensively studied as it was not considered of economic importance.

DR. HOLMES, in reply to a question posed by MR. K. B. ARMSTRONG, said that the original recommendation for the control of sawflies overwintering on field margins was burning, but it had been found that they usually escaped. Stubble had to be buried at least six inches deep, and, although deep ploughing was not possible in the area under consideration, normal cultivation in the fall did kill a few. Marginal trap plots were sometimes of value, but farmers were loth to cut the grass to waste.

The CHAIRMAN said, in opening the discussion on Mr. Fennah's paper, that he had been impressed by this approach to an entomological problem; few realised that plants required other additives than water—and even then it was far from easy to know whether a plant had enough water or not.

MR. J. FORSYTH asked for further information on the way in which the nutrients had been injected, what had been injected, and how much. MR. FENNAH said that his original experiments had been based on Roach's technique [W. A. Roach, 1938, *Tech. Commun. Bur. Hort. E. Malling*, no. 10], and were later simplified to include only nutrients believed to be lacking or even water alone. A fully grown cacao tree would take up about twenty litres in twenty-four hours, but in citrus branches about a litre had been found sufficient for twenty-four-hour imbibition and the use of single branches had the advantage of allowing un-injected branches to be used for comparative purposes. The secret of efficient injection, as a technique, was good carpentry—a clean-cut hole—for the quantities actually imbibed were the important factor in work of that type. No difficulties occurred when injections could be made under pressure, and in cacao the advisable upper limit was about 90 lbs. a square inch.

MR. FENNAH, in answer to a question put by MR. D. P. ANNECKE, said that the succession of Coccids described by him were observable as such in the field, with *Lepidosaphes* succeeding species of *Saissetia*, which themselves succeeded *Coccus viridis* (Green), especially on neglected citrus trees. The occurrence of *C. viridis* on fully mature leaves was regarded as a bad symptom, as citrus so affected was seriously in need of agronomic amendments, and, if neglected, could be expected in Trinidad conditions to deteriorate to the final stage when the tree consisted of scarcely more than a framework supporting birds' and wasps' nests. The CHAIRMAN wondered how far some of the insect distributions illustrated and described had been due to the nutrients available in the plant and how far to alterations in the microclimate.

MR. FENNAH explained that in his own experiments the treatments were designed to expose the insects to as wide a range of microclimate as occurred in the field, in order that the influence of light intensity, heat, humidity, position in relation to gravitational stress, air movement and substrate texture could be evaluated. Response to such factors did not occur, or was slight, within the range of values normal in field conditions. In one investigation the response of the insect was elicited at pre-selected times, and followed catabolic changes which were induced, and followed analytically, in the solutes of the leaf substrate.

MR. T. LEWIS asked whether the thrips moved from the yellow-green part of the intervenal area of a cacao leaf on which they had been feeding to adjacent dark-green areas as those began to turn yellow.

MR. FENNAH replied that areas of the kind illustrated in his slide had resulted from local damage by insolation. The remaining part of the intervenal area was not damaged, and accordingly, like any other normal leaf tissue, would only become yellow in the very last stages of leaf senescence, a time well past the stage at which it might be colonised by cacao-thrips. Cacao-thrips placed on healthy dark green tissue did not turn it yellow by feeding. Any response of cacao-thrips to the colour of the leaf substrate seemed to be of negligible importance. For example, the insect did not attack healthy young cacao foliage in the flaccid stage of early flushing whether the foliage was red, yellow-green or pallid grey-green. Yet it could readily attack such leaves, irrespective of their colour, if they had been prematurely aged by induced deficiency of minor elements.

DISCUSSION ON RECENT INVESTIGATIONS ON TIMBER BORING BEETLES

Chairman: DR. M. L. ROONWAL, *Director, Zoological Survey of India*

MR. E. O. PEARSON announced that Mr. Bletchley had been delayed and that therefore the paper by Mr. Tecwyn Jones would be read first. The CHAIRMAN said that Mr. Jones, who was currently in the East African Agriculture and Forestry Research Association, was formerly a member of the Timber Borer Research Unit in West Africa, and it was with some of the work which he carried out while stationed there that he was about to deal.

Ambrosia Beetle Research in West Africa

By MR. TECWYN JONES

Formerly Officer-in-Charge, West African Timber Borer Research Unit, Kumasi, Ghana

In January 1953, a team of three entomologists assembled at the Forest Products Research Laboratory for a brief period of post-graduate training. Their arrival at Princes Risborough signified the formation of the West African Timber Borer Research Unit and as such marked an important stage in the expansion of forest products entomology within the British Commonwealth.

As far back as 1935 Professor Munro had drawn attention to the growing problem of ambrosia beetles in tropical hardwoods and had recommended early investigation. This advice, though generally unheeded, proved to be very sound, when in 1938 the ambrosia beetle problem in Nigeria became acute. The situation in that territory indeed caused such grave concern to both the Forest Department and the timber trade that the Chief Conservator sought the help of the Forest Products Research Laboratory and asked the late Dr. R. C. Fisher to formulate proposals for a thorough investigation of the Nigerian problem.

With the intervention of World War II, however, these proposals were left in abeyance until in 1949 when, formulated as a three-year scheme, they were approved by the Committee for Colonial Agricultural, Animal Health and Forestry Research. By 1952 full details for an interterritorial scheme, involving both Ghana and Nigeria, were finalised. They envisaged the establishment of two entomologists in West Africa and one in the United Kingdom and the estimated cost for the first three years was given as £15,000. The West African Governments unhesitatingly accepted this scheme and agreed to contribute their share towards the cost of investigations. With these funds and an equal contribution from the Colonial Development and Welfare Fund, WATBRU came into being.

Its inception, however, was long overdue because by this time the tropical hardwood trade, particularly in West Africa, had expanded to an unprecedented degree and the degrade of timber resulting from ambrosia beetle infestation had reached alarming proportions. It was estimated, for example, that losses in Ghana alone amounted to more than a million pounds per annum, *i.e.*, approximately 15 per cent. of the total value of its timber exports. Our knowledge of the biology and control of the pests on the other hand was still meagre and only limited progress had been made over the past ten years. Browne in Malaya had made a valuable contribution to our knowledge of the Malaysian species and certain Colonial Forest Departments had conducted a few insecticide trials in conjunction with Dr. Fisher and his staff at Princes Risborough. Apart from these instances, there was little data available which might be applicable to West Africa. For the two-man Unit that sailed for Ghana in July, 1953, this meant in the first place surveying the problem; collecting and identifying the pests; determining the susceptibility of the host timber and from biological and ecological studies assessing the relative merits of various control methods. These main projects together with their inevitable side lines were incorporated in the terms of reference of the Unit which were:

> " to elucidate the biological and ecological background of the West African Scolytoidea and to develop some economic method of controlling them."

There was yet another aspect of the ambrosia beetle problem, however, namely the determination of the relationship between the beetles and the so-called ambrosia fungi on which they feed. It was thought at this stage that it might be possible to control the beetles indirectly by controlling the fungi, but first the specificity of the latter had to be ascertained. This basic study required mycological and entomological facilities and so formed the programme of work of the officer of the Unit who remained at the Forest Products Research Laboratory. A review of these investigations which were conducted by Mr. J. M. Baker is incorporated below (p. 94).

A REVIEW OF WORK IN WEST AFRICA

It was immediately apparent that the need for some method of log protection was urgent in both Ghana and Nigeria, but it was equally clear that the development of even the most palliative control measure would only be possible when certain ecological aspects of the problem had been clarified. Priority was therefore accorded to the elucidation of the incidence of ambrosia beetle attack and the various factors governing its intensity. Some time later, when conclusive results had been obtained from these early investigations, chemical control methods were initiated. These, together with further ecological studies, were then pursued simultaneously and this pattern has been continued to the present day. Both aspects of the problem are, of course, interdependent to a considerable degree, but for the purpose of this paper it is more convenient to discuss them separately.

Ecological Investigations

The first experiment was designed to assess the incidence and degree of infestation in relation to time, condition of the host, and conditions of exposure to attack.

Trees of two highly susceptible genera, namely *Antiaris* and *Albizzia*, of widely differing girth sizes, were felled at monthly intervals over a period of some eighteen months. Each tree was cross-cut into eight billets, each of four-foot length, and these were exposed to attack under all combinations of the following conditions: with bark intact and with bark removed; exposed to the sun and under shade; on the ground and raised on skids or sleepers. Ambrosia beetle attack was assessed each week by the number of entrance holes on sample square foot areas on the topside, underside and lateral areas of each billet, and counts were continued over a period of twenty weeks. From data obtained the following conclusions emerged.

(i) Ambrosia beetle attack usually occurred within twenty-four hours of the tree being felled, and frequently within an hour of felling.

(ii) The increase in density of attack over the first twenty weeks after felling was generally steady and regular with no marked increase or decrease at any particular stage. After twenty weeks the density of attack could exceed 1,000 holes per square foot of log surface.

(iii) Logs devoid of bark sustained significantly heavier attack than logs with bark intact. This difference was more apparent in the earlier stages of exposure than later.

(iv) There was no correlation between girth size and the severity of the attack sustained.

(v) There was no significant difference in the attack sustained by logs exposed to the sun and logs in shaded conditions.

(vi) Attack on the topside, underside and lateral areas of logs differed in density but no surface was consistently more heavily attacked than others under the same condition of exposure.

(vii) Logs in contact with the ground were more heavily infested than those raised on skids. (This was particularly evident from comparisons of attack on the underside of billets in the two conditions.)

(viii) The cross-cut surfaces of logs sustained very heavy infestation at an early stage, but most of these attacks proved abortive.

Concurrently with this first experiment, others of much shorter duration were initiated to determine the relative susceptibility of the commercially important timbers and the factors governing their susceptibility. These projects were conducted in the various forest types of Ghana and Nigeria at intervals from 1954–59.

The method of investigation involved felling one tree of each important timber in the selected area, and cross-cutting each tree into the appropriate number of billets in accordance with the requirements of a Latin Square design. The logs were exposed to attack for a period of six weeks and susceptibility was assessed on the basis of the infestation per square foot of log surface. In the earlier projects, billets with bark intact and others devoid of bark were included, but later this proved unnecessary and only debarked billets were used. Likewise, in the first few experiments, the starch and moisture content of each species was assessed at felling and at the end of the experiment while certain physical features were also noted. As no significant correlation was found between these features and the density of attack, these observations were discontinued.

From the results obtained it was possible to compile a susceptibility index for the West African timbers, in which each species could be rated as of high, moderate or low susceptibility. The rating of an individual species in a few cases varied from one type of forest to another, for example *Antiaris africana*, which was consistently a highly susceptible species throughout Ghana, was of low susceptibility in Nigeria. With this exception, however, the susceptibility index obtained was remarkably consistent, and has proved a reliable guide to the timber trade of West Africa.

Apart from this index, which has been published in detail elsewhere, the following points emerged from these susceptibility trials.

(i) The sixty-odd host species used in this experiment exhibited markedly different degrees of susceptibility to beetle attack, but no species was immune to infestation.

(ii) No correlation was found to exist between the degree of susceptibility of the host and its starch content, moisture content, sapwood to heartwood proportion, its bark thickness or its wood density.

(iii) Degree of susceptibility likewise shows no correlation with botanical groupings, *i.e.*, members of the same family may exhibit widely different susceptibilities.

(iv) Although no correlation was established between girth size and density of attack, it was apparent that whereas Scolytidae preferred small-size billets the Platypodidae were generally confined to the larger logs.

Another important aspect of ambrosia beetle ecology was the seasonal fluctuations in population and the factors influencing population build-up.

Seasonal variation in attack on logs was evident from the first experiment which extended over one complete climatic cycle. The figure obtained indicated that peak infestation occurred in January and to a lesser extent in May, *i.e.*, during the drier periods of that particular year. The experiment, however, showed all the limitations of one-season sampling and hence the results were not necessarily typical.

In view of this, further investigations were carried out in 1957, when greased cloths and cylinders were used in place of bait logs. Two different sites were utilised for trapping. At one site a small group of trees were poisoned with sodium arsenite, thus producing highly attractive conditions for the beetles, and surrounded by greased cloths and cylinders. By this method it was hoped to obtain a fair sample of the beetles approaching the trees and also at a later date a sample of the emerging progeny. At the other site, the grease traps were suspended in straight lines through the forest, at ten-yard intervals. From the catches obtained, the weekly and monthly fluctuations in the general ambrosia beetle population, and the variation in numbers of individual species were examined, in relation to temperature, humidity and rainfall. Unfortunately this experiment was unavoidably suspended in 1958 and at the time of writing investigations, although restarted, are still incomplete but the following interim results can be given.

(i) Considerable variation in the total population was apparent and the numbers of each individual species also varied considerably throughout the year.

(ii) No correlation was established between these variations and temperature or humidity.

(iii) On the basis of monthly catches rainfall seemed to influence the number of beetles on the wing, but as this was not confirmed by weekly catches it is doubtful if rainfall in itself has an influence on beetle abundance. It seems rather that some factor associated with the wetter periods of the year favours beetle activity.

With regard to the condition conducive to population build-up, it had been observed that although normal felling operations promoted the development of higher population by providing abundant breeding material, the practice of poisoning trees with sodium arsenite or hormones seemed exceptionally favourable to the beetles. It was very evident, for example, that in the Bobiri Forest reserve where the poisoning of weed trees had been continued over several years, that the beetle population was considerably higher than that in areas of forest where no poisoning had been carried out. Preliminary experiments showed that a very significant increase in population could occur in poisoned areas of forest within a year of poisoning operations. More recent and more extensive investigations, as yet incomplete, tend to confirm this.

A logical sequence to the study of seasonal activity was the investigation of diurnal rhythms or flight periods. Experiments were carried out periodically over several years using both bait logs and grease traps in which the arrival of beetles was recorded at hourly intervals throughout the day and night. A wealth of biological information on individual species was obtained in this way but here it will suffice to summarize the observations on diurnal rhythms.

It was found that the majority of Scolytoidea were crepuscular in habit and appeared on the wing for only a brief hour or two at dusk and dawn. By far the greater part of the population appeared on the wing in the evening. A few species were entirely nocturnal, appearing only after the onset of darkness and continuing until the very early hours. An even smaller number of species appeared only during the mid-day period when temperatures were high and humidity was low.

Time of flight could not be correlated with temperature nor with humidity or rainfall when these factors were considered separately but in the case of crepuscular species there appeared to be some connection between flight and the prevailing saturation deficit.

Several other ecological investigations were undertaken, for example, the pattern of attack on poisoned trees and the direction and level of ambrosia beetle flight within and without the forest canopy. Much fascinating biological data was accumulated on the method of infestation, courtship, care of the brood, and the different role of the male in the Scolytidae and Platypodidae. Gallery patterns of several species were determined and the length of life cycle assessed. All these, however, had no particular significance in determining the way in which ambrosia beetles could be controlled and so need no more than this brief mention here. Before leaving them, however, it is necessary to make the important point that predators such as Cleridae, Brenthidae and ants, although frequently occurring in abundance, were never observed to reduce the population of borers by any significant degree.

The Relation of Results to Possible Methods of Control

In considering the best way of preventing attack on logs, *i.e.*, developing a cheap and efficient method of log protection, the following conclusions from the ecological studies mentioned above, were particularly significant.

First, beetle attack commenced almost as soon as the tree was felled and continued to increase in severity for at least twenty weeks. Control measures therefore were necessary from the earliest stage of exploitation, *i.e.*, at the stump. Secondly, attack continued throughout the year and hence there was no safe period for exploitation when control measures could be ignored. Thirdly, logs of all the important timbers were liable to attack on all surfaces, and hence no timber could be exported without protective treatment and this treatment had to include both rounded surfaces and cross-cut ends. Fourthly, the trade practice of removing the bark from freshly felled logs was highly conducive to heavy infestation by Cerambycidae and Buprestidae which occur in abundance in the forests of results.

Bearing these facts in mind, it was apparent that only improved handling methods or chemical control measures were likely to provide an effective means of log protection. Rapid extraction of logs from the forest would obviously reduce the severity of attack and if conscientiously employed could even provide completely clean timber. The essential requirement in this case was perfect co-ordination between felling and extraction—an ideal rarely, if ever, attained in the wet conditions of West Africa. In conjunction with rapid extraction and to some extent in place of it, the practice of leaving bark intact on freshly felled logs would reduce the severity of ambrosia beetle attack, but then other detrimental conditions obtained. Bark retards ambrosia beetle infestation but its presence on a log permits heavy infestation by Cerambycidae and Buprestidae which occur in abundance in the forests of West Africa. These borers, although rarely penetrating to the heartwood of timber, cause such spectacular damage to the sapwood and to the log surface that logs are severely devalued by their unsightly appearance.

From this it was clear that apart from rapid extraction which is generally impossible there was no managerial method of preventing attack on green logs, and recourse to chemical methods was obligatory.

Investigation of Chemical Control Measures

To be successful any chemical method of log protection had to meet the most stringent requirements. It had to be easily applicable in the forest, at the gantry site or at log piles in the sawmill. It had to be highly effective and in efficiency at least approach 100 per cent. control. It had to persist for several weeks under conditions of heavy rainfall, and in Nigeria, where logs are floated in rivers from forest to sawmill, it had to withstand even more severe leaching.

With these requirements in mind a series of trials were carried out from 1954 onwards using various formulations of insecticides and a few wood preservatives. The first fact that emerged was that the efficiency of basic ingredients not only varied with their formulation but also with the surface to which they were applied. This was particularly evident in the case of oil solutions of γBHC, aldrin, endrin and dieldrin which, though efficient on logs from which the bark had been removed, were much less efficient on logs with their bark intact. These contrasting results were thought to be due to an inter-reaction between the oil and the bark, and investigation proved this to be the case. It was found that oil alone when applied to fresh logs with bark intact, rendered those logs much more attractive to ambrosia beetles than freshly felled untreated logs. One theory to explain this remarkable phenomenon is that the oil gradually destroys the bark chemically if not physically, and thus permits the rapid release of substances attractive to ambrosia beetles which would otherwise remain enveloped and masked by the bark. This theory is attractive and is even more acceptable perhaps in view of the established fact mentioned earlier that the removal of bark from fresh logs renders those logs highly susceptible to beetle attack.

Water emulsions and water miscible paints incorporating the same basic ingredients as the oil solution, showed no significant difference in efficacy on logs devoid of bark or logs possessing bark. Complete coverage was more easily obtained on logs from which bark had been removed, and in all later experiments it was only logs of this condition that were used.

Trials to compare the efficacy of basic ingredients on debarked logs produced highly conclusive results. Aldrin, endrin and particularly dieldrin were highly persistent but at any given concentration never attained the level of control provided by γBHC irrespective of formulation. γBHC proved highly effective in Ghana when formulated as a water emulsion, water paint, oil solution or as an oil and resin mixture, and although less persistent than other insecticides it nevertheless gave over 95 per cent. protection for ten weeks when used at a concentration of not less than 0.75 per cent.

Similarly in Nigeria γBHC was much more effective than aldrin, dieldrin and malathion. There however, where the logs were partly submerged in water, aqueous emulsions, water paints and even oil solution were generally ineffective and only grease or oil-bound paint formulations gave the necessary persistency. To date γBHC at 0.75 per cent. concentration incorporated in oil paint and applied by brushing has provided over 95 per cent. protection for a period of ten weeks.

From these results it was possible to formulate an effective programme of log protection for both Ghana and Nigeria which can be summarised as follows. If rapid extraction of the logs is impossible then the bark should be removed and 1 per cent. γBHC applied by spray or brush to all surfaces. In Ghana, where road and rail transport is employed, water emulsions are adequate, but in Nigeria, where water transport is usual, oil-bound paints or greases are recommended.

Recent Extensions of Investigations

In 1957–58 when measures for ambrosia beetle control were reasonably well established the Unit, at the request of the timber trade, extended its investigations beyond its original terms of reference to include pests of sawn timber and lumber. These pests, the Bostrychidae and Lyctidae, cause serious losses in West Africa, and the first stage in their study, *i.e.*, the survey of the distribution and relative importance of each species, is now nearing conclusion. Biological studies of individual species are well under way and the significance of starch content of standing and felled trees in relation to powder post beetle attack is also being investigated.

Expansion into this new field of study was facilitated in 1959 when the administering Governments approved proposals for the expansion of the Unit in West Africa. These proposals made provision for an increase in the senior staff establishment to include an additional entomologist and a biochemist, and an appropriate increase in African field staff. The newly created senior posts have yet to be filled but the additional junior staff and an increased budget have already permitted the Unit to comply more closely with urgent requests of the timber trade. Indeed it was in compliance with such a request that the Unit undertook investigation of the so-called " borer of living Wawa." A large percentage of sound-looking trees of *Triplochiton scleroxylon* (Wawa) in Ghana are found on conversion to be damaged internally by black stained tunnels of an unknown ambrosia beetle. These tunnels in themselves cause serious degrade of Wawa but bluestain which enters the tree *via* the beetle tunnels causes even greater devaluation of the wood. The whole problem is made more difficult by the fact that there is usually no external indication of the damage within the tree because the original entrance hole of the beetle becomes occluded by the growing tree soon after the insect has successfully completed infestation.

Recently Roberts, who conducted the Unit's investigations on this problem, obtained living specimens of the Wawa borer and these have been described by Schedl as a new species, *Trachyostus ghanaensis*. This success was followed up by some fruitful investigations, the results of which can be briefly summarised as follows.

(i) *Trachyostus ghanaensis* is host specific, being confined to *Triplochiton* and can only inhabit living trees.

(ii) Trees are attacked when between 2–3 ft. girth and attack can continue throughout the life of the tree.

(iii) Infestation is heaviest in trees between 5 and 7 ft. girth and tends to decline from then on with increase in girth size.

(iv) The beetle occurs in *Triplochiton* areas west of the River Volta but is absent from the same species east of this river. Thus it occurs in Ghana and Ivory Coast and not in Togo, Dahomey, Nigeria and Southern Cameroons. This can probably be explained by the absence of *Triplochiton* in the Dahomey Gap—an area of low rainfall and humidity.

(v) The abundance of the insect in Ghana seems to be determined by the type of forest, *i.e.*, it is abundant in thick forest but scarce in *Triplochiton* growing in forest areas opened up by farming.

(vi) *Triplochiton* growing under unfavourable conditions—particularly in areas of poor drainage—is very heavily attacked.

(vii) Chemical control is virtually impracticable and only silvicultural or biological methods hold any promise of success.

Conclusion and Future Research

From the above review it is apparent that there are still some very large gaps in our knowledge of the West African Scolytoidea. One particularly basic and fascinating problem remains unsolved, and that is the phenomenon of beetle attraction to their host. This requires the combined efforts of the entomologist and the biochemist. With the recently increased establishment of the Unit it is hoped that the requisite team will soon be acquired and commence investigations under the experienced guidance of F. G. Browne who has joined the Unit from Sarawak.

Despite such deficiencies in our knowledge, however, considerable progress has been made in a field which in 1953 was virtually untouched. The Unit's contribution to our knowledge of the biology and ecology of ambrosia beetles though incomplete has been highly significant and has formed the basis on which effective control measures have been developed. The fact that an efficient method of log protection has been presented to the timber trade of West Africa is in itself ample justification for the time and money devoted to the problem.

A Review of Work at the Forest Products Research Laboratory (by Mr. J. M. Baker)

This work was supplementary to that in West Africa and was undertaken with the object of elucidating some of the more fundamental aspects of ambrosia beetle biology. Studies were aimed at building up a picture of the behaviour, development and fungal relationships of *Platypus cylindrus* (a typical Platypodid), to determine the nature of the tunnel flora and to discover the factors influencing the attraction of the insect to stumps and logs in which it bores. The following is a very brief account of the conclusions which emerged.

Infestation and Life Cycle of *Platypus cylindrus* F.

P. cylindrus is typical of its family in that the male initiates infestation, and once joined by the female takes no further part in boring the tunnels. Two types of bore dust are produced, namely fibrous or splintery dust and granular dust. The fibrous type is most typical of the initial borings and is produced by the adults. Granular dust, which appears some time after the establishment of the tunnels, results from borings by larvae or by females whose mandibles have become worn and blunted. Immature adults take no part in extending the tunnel system.

Flight, and consequently, infestation of new hosts normally occurs in July and eggs are laid in August, but where infestation is delayed until the autumn oviposition may not occur until the following spring. The eggs hatch after two to six weeks and the emerging larvae are typically flattened and ovoid. After several weeks these pass through intermediate instars to the final stage larva which has characteristic dark sclerotised thoracic plates. The number of instars between egg larva and pre-pupal larva is two or three, but exact determination is difficult because the breeding of larvae from egg to adult is impossible and furthermore measurements of head capsules, although carried out on over five hundred larvae, showed that instars could not be determined by plotting a frequency distribution histogram of head width sizes. Pupation normally occurs in May and adults appear in late June. If pupation is delayed until autumn then the teneral adults remain in the gallery until the following June. The life cycle therefore is of one or two years' duration.

Anatomical Studies

The alimentary system of larvae and adults, and the female reproductive system is similar to that of various Scolytidae. The male reproductive system on the other hand is less complex than most Scolytidae.

The central nervous system shows considerable condensation, the meso and metathoracic ganglia and all the abdominal ganglia are united in the metathorax. Two pairs of nerves are given off to the abdomen, five further pairs to the meso and metathorax and three pairs arise from the prothoracic ganglion.

Variations in the condition of the reproductive organs at different stages in the life history were studied in some detail. At emergence both male and female are mature. Copulation takes place once only, *i.e.*, at the time of initial infestation of the host, and from that time the female stores sperm in the distended spermatheca. Spermatozoa are released slowly throughout life, *i.e.*, over a period of at least two years and in old females the spermatheca becomes deflated and almost empty. At the onset of egg-laying the four ovarioles each contain 2–4 oocytes, but the number increases as the size of the tunnel system increases until in extensive tunnels each ovariole may contain 10–15 oocytes. *Corpora lutea* appear on the pedicels of ovarioles just after oviposition but as they soon disappear they are unreliable indications of the egg-laying state of the beetle. The male organs remain apparently fully active for two or even three years.

Flight Times and Populations.

Peak emergences occur in late July and early August but beetles continue to emerge sporadically throughout the autumn and winter. More beetles emerged during warmer days (*i.e.*, over 22°C) than in cooler periods but no correlation was established between emergence and temperature or humidity. Peak flight periods occur between 10 a.m. and 4 p.m. G.M.T. The number of male and female emergents was approximately equal.

The number of emergents per tunnel varied from six to twenty but an even greater population remained within the host. The average density of population in one Turkey oak log, fourteen to sixteen months after initial attack, was 800–900 larvae and adults per cubic foot.

Fungal Relationships

A fungus of unkown species consistently isolated from tunnels and insects by various methods including germination of single chlamydospores had some very close affinities with the fungi known to medical mycologists as *Sporotrichum* but as the taxonomy of this genus is unsettled it is more prudent at present to refer to this particular ambrosia fungus by its collection number, *i.e.*, A200.

All stages of this fungus occur in tunnels of *P. cylindrus*. In some branch tunnels a dense pilose layer occurs, with many conidia, sterile hyphae and some chlamydospores. In this state the fungus is ready for browsing. After browsing only old hyphae are left and later regeneration gives rise to a stroma lining the tunnel wall and on this a layer of finely comminuted wood is built up through which new hyphae grow and fruit. This irregular lining is browsed and quickly becomes renewed because the wood fragments removed are replaced by others from the faeces of the insect and the fungus ramifies through this new layer. The chlamydospores pass through the gut of the beetles undigested and germinate in the tunnel lining. They undoubtedly help to maintain the active growth of the fungus but why they occur only in some parts of the tunnel is not known.

Three other fungi are regularly associated with *P. cylindrus*. One, of the genus *Endomycopsis*, grows profusely in new tunnels but is soon dominated by A200. Another fungus, *Cephalosporium*, A71, which in its early stage resembles *Leptographium lundbergii* occurs in tunnels with marked regularity and is often found in stained areas of wood, but its role in tunnel economy is not clear. Finally, an anascosporogenous yeast, known as A15, occurs in tunnel slime and in wood elements such as parenchyma cells which open into the tunnel. Other fungi, including species of *Ceratocystis* and their imperfect stages, *Graphium* and a *Cephalosporium* of different form to A71, grow in diffuse stained wood around the tunnels and some of their spores are eaten by the insects. The fungus, *Coryne sarcoides*, is responsible for diffuse stain near the tunnels.

Several species of *Penicillium, Paecilomyces, Fusarium, Stysanus, Botrytis, Trichoderma*, Mucorales and various wood-rotting Basidiomycetes were also isolated from tunnels. *Penicillium, Paecilomyces* and *Trichoderma* were found in declining colonies and appear to be incompatible with healthy tunnels. Basidiomycetes rarely occur even when wood quite close to the tunnel is rotten and it would seem that some antagonism exists between tunnel flora and wood-rotting fungi but this could not be illustrated in artificial culture.

Transport of Fungi by the Insect

It was found that the head, thorax and elytra of males and females all carried the four common tunnel fungi mentioned above. Fungi were carried on the hairs of the frontal region of the head and on the long hairs of the mouth parts. On the thorax it was the tegumental folds of the meso-and metanotum and the sternal hairs between the coxae which bore the fungi. On the elytra fungi were carried among the hairs of the declivity and on the underside of this region while A200 and A15 were found to be not uncommon in the hind gut.

Food of the Insects

Wood particles occur in the gut of larvae and adults but there is no evidence of the cell wall material being digested. In the crop abundant fungal material was found including hyphal tips, spores of *Sporotrichum, Cephalosporium* and *Endomycopsis, Ceratocystis* and *Graphium* and yeast cells of A15.

In the hind gut of larvae wood particles were again present and in the same undigested condition except that the yeast cells in the lumina of the wood elements were broken up and partially digested. All dense young hyphae and ascospores had disappeared and many, but not all, of the thin-walled spores. Most thick-walled chlamydospores passed through the gut undigested while oidial chains of A200 were common in the rectum and were able to grow there.

In adults larger wood particles occurred in the crop; they, together with their attached mycelia, became finely divided by the gizzard. As a result of this the contents of the mycelia were digested but, as in the case of the larvae, the cell walls were not digested.

Attraction of Beetles to their Host

Using petroleum ether extracts of oak attempts were made to determine and isolate the substances which attract *P. cylindrus* to logs and stumps.

Wood from logs which had recently been attacked was used to prepare one series of extracts and wood from logs which, though exposed to attack, had remained unattacked by the beetles was used for another series. A simple olfactometer was designed in which an aspirator drew a stream of air at a controlled velocity through a charcoal tower to remove any odours, then through a porous block containing the extract, and finally along a tube into which the insect could be introduced. The tube had a floor of corrugated filter paper which the insect could walk on, and was of sufficient diameter to give it room to fly. In some experiments fresh chippings of bark and wood were used in place of the extract.

The results showed no evidence that any of the preparations were either attractive or repellent; they did, however, show a tendency for the beetle to move against the air stream. Some of the extracts of the two series were sent to the Chemistry Department of Edinburgh University for anaylsis by gas chromatography, but it was not possible to demonstrate any difference between the two series.

It seems unlikely that these two methods as they stand are capable of yielding results. With the extraction apparatus if quite large bolts of oak could be used, encased, say, in plastic sheeting, and a slow current of gas passed over them and fed directly into a gas chromatography apparatus instead of into a condensing trap, then it might be possible to detect the attractants.

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The Susceptibility of Hardwoods to Lyctus Powder-Post Beetles and Methods of Control

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A Commonwealth Entomological Conference affords an appropriate occasion to review literature on the biology and methods of control of *Lyctus* powder-post beetles, which cause severe damage to sapwood of susceptible hardwoods throughout the world. Annual financial losses resulting from *Lyctus* attack have been estimated at $15,000,000 in the United States of America and at £1,000,000 in South Africa (Mason, 1952). The problem has varied with changes in supply of hardwoods, methods of handling, and utilisation. Before World War II the United Kingdom timber trade was largely concerned with infestations in imported American hardwoods. During the war accumulated national stocks of hardwoods provided ideal breeding grounds for these beetles. Following the war the utility furniture scheme, designed to meet an immediate shortage, necessitated inclusion of a high proportion of sapwood and resulted in some serious infestations. Subsequently, greater availability of timber has improved standards of quality. However, employment of susceptible timber in flush doors of blockboard construction, increased use of West African and other light tropical hardwoods for joinery and plywood cores, and the popularity of strip and wood block floors, have provided new problems. Use of cheaper tropical timbers in crates and packing cases and the development of palletisation have provided suitable material for infestation, which has seriously affected bulk storage in warehouses not only in the United Kingdom but elsewhere (Taylor, 1950). Secondary damage may result from the collapse of packing cases at the base of a stack and the bursting of tins contained therein through the superimposed weight, or woollen or other stored goods may be damaged by beetles emerging from infested shelving (Freeman, 1952). Weakening of structural timbers in the United Kingdom (in contrast to some other Commonwealth countries) is rare, mainly because softwoods are widely used, but where large dimensioned hardwoods are employed and sapwood is retained, it is usually seasoned in log form (the starch content being thus often depleted) and therefore other species of wood-boring insects (chiefly Anobiidae) are normally responsible for structural damage. Exceptions have occurred: for example, *Lyctus* damage in quickly dried oak sapwood offcuts used for tile battens.

Lyctus spp. occur in both temperate and tropical countries but *L. brunneus* (Steph.) (an American species) has become widely established and in the United Kingdom is now much commoner than the native species *L. linearis* (Goeze) (Fisher, 1928). For this reason studies have been concentrated on the biology and control of *L. brunneus*, to which this paper is mainly confined.

Life-cycle, Habits and Nutritional Requirements of *Lyctus brunneus* Steph.

Detailed studies on this species have been carried out by Parkin (1934, 1936, 1940, 1943) at this Laboratory and more recently by Gay (1953) in Australia. Data provided by Parkin formed the basis of a technique, now standardised at the Forest Products Research Laboratory and recently described by my colleagues E. C. Harris and Miss Taylor (1960), for providing a continuous supply of all stages in the development of this species throughout the year under controlled conditions of 25°C. and 75 per cent. relative humidity, with a completed life-cycle reduced to a period of three months. This work has been further developed by Miss Taylor (1960b) into a standard technique for testing wood preservatives. Early attempts to use *L. brunneus* as a test insect failed through lack of knowledge of its nutritional requirements.

A review of the progress of these investigations, from the initial summary by Fisher (1928) through the fundamental studies by Parkin to the development of a preservative testing technique, emphasises the necessity of basing applied work on a sound knowledge of the biology of the species concerned. For example, adult activity is related to temperature and light, the beetles becoming very active at higher temperatures but hiding during the day in crevices or old flight holes, behavioural characteristics of significance when testing the effect of contact insecticides. Investigations on the relationship between the diameter of wood vessels, within which the eggs are laid, and the diameters of egg and ovipositor have explained why some timbers are attacked and not others. Clarke (1928) concluded that where wood vessel diameters were less than those of *Lyctus* eggs the timber remained immune; subsequently certain anomalies were detected. These were explained when Parkin (1934) found that the normal dimensions of the egg were adjustable to facilitate its insertion into the vessel and the true limiting factor was the diameter of the ovipositor. Knowledge of the depth (7 mm.) at which eggs can be laid in this way is important in relation to the depth of penetration required for preservatives without fumigant effects. Fisher (1952) recorded an interesting case of *Lyctus* attack in a softwood (normally considered to be immune owing to the absence of large vessels and limited starch reserves): in an attacked sample of *Pinus canariensis* from South Africa adequate starch was present and it appeared the resin ducts had been utilised for oviposition.

Data on the moisture content of wood limiting its suitability for egg-laying have also been obtained. Parkin (1943) found that eggs could hatch and larvae develop at a moisture content as low as 7·7 per cent., but as green timber could be attacked as soon as the surface had dried sufficiently, it was impracticable to specify an upper limit; however, he found that survival was possible in timber with a moisture content below fibre saturation point at about 30 per cent.

Although Parkin (1940) has shown *L. brunneus* to be mainly a cell content feeder, a conclusion reached by Campbell (1929), many problems remain for investigation; for example, the purpose of the mycetomes, unconnected with the gut, and the nature of an unidentified substance which when leached from susceptible oak blocks rendered them unsuitable for normal larval development (Parkin, 1936). Further studies on this substance might explain why some timber species with sufficient starch and vessels suitable for *Lyctus* oviposition are not or are only lightly attacked (Brimblecombe, 1945). It is probable that the substance (or substances) are not sugars since it would seem likely that *Lyctus* could obtain these requirements from starch. Since Hopf (1937) confirmed the necessity of adequate nitrogen for larval development, it is possible that the essential substance may be of a nitrogenous nature.

Prevention and Control of Infestations

Prevention

Removal of sapwood is uneconomic except where it is narrow and would be impracticable in species with no obvious distinction between sapwood and heartwood. Since starch is one of the essential food requirements of *Lyctus* larvae, its removal would render any further preventive measures redundant. Much thought has, therefore, been given to methods of starch depletion. Such studies necessitated data on variations in starch content within a tree and at different times of the year, and to facilitate this a visual method of grading was devised by Phillips (1938). The method does not provide an accurate quantitative assessment but furnishes an adequate although arbitrary determination of susceptibility to *Lyctus* attack. Phillips found maximal quantities of starch at leaf fall and in early spring but the relative amounts differed between deciduous and evergreen species. Brimblecombe (1945) also found two peaks in starch content occurred in evergreen trees in Queensland but found no relationship to flowering and fruiting. Wilson (1935) pointed out that the fate of starch reserves depended on the treatment the timber received after felling—quick conversion, drying and consequent death of the cells inhibiting starch depletion.

The following methods of removing starch have been investigated: (1) girdling of standing trees; (2) storage of timber in the round complete with bark; (3) storage of freshly felled timber under water, and (4) adjustment of kiln drying schedules for green converted timber. The rate of depletion is governed by the temperature, moisture content and rate of gaseous exchange through the wood (Parkin, 1937a), but may vary between one species and another owing to specific differences in the properties of the starch or in the enzyme systems (Phillips, 1938).

Hartig showed in 1859 that starch depletion occurred below a ring cut in a growing tree. Mer in 1903 indicated that the most rapid resorption of starch occurred where trees were double girdled at the top and bottom of the trunk and was best carried out in June when starch was at a minimum. Parkin (1938 a and b) concluded that girdling oak was an unreliable method of securing starch depletion, and Parkin and Phillips (1939) found the method increased the variation in starch distribution throughout a tree. K. L. Taylor (1948) concluded high girdling was a commercial possibility in the case of spotted gum in New South Wales but probably not in rain forest species. This difference may be due to a narrow sapwood in the former resulting in a smaller quantity of starch to be resorbed.

Browne (1938) pointed out that log seasoning exposes wood to attacks by numerous other insects and fungi and was impracticable under Malayan conditions. Water storage may be more suitable in some cases but exposed areas of logs are liable to ambrosia beetle infestation. A more promising method of starch depletion by accelerating the natural katabolic processes of the living cells was investigated by Henderson (1935, 1943) who found that the optimum temperature was 41°C. in ash but at 45°C. death of the cells prevented further reduction. Opinions are sometimes expressed that kiln drying produces continued susceptibility of sapwood through death of the cells and fixation of starch. My colleague, E. C. Harris, has made comparisons between rates of starch depletion in air dried and kiln dried European oak and found that, on the contrary, much greater resorption could be produced by kiln schedules commencing at 40·5°C. and 85 per cent. relative humidity (1961). Where susceptible hardwoods are used for structural purposes but receive no chemical preservative treatment or surface finish (giving mechanical protection against oviposition), such a method of starch depletion may be practicable where adequate kiln drying facilities exist. On the other hand, timbers, dried at schedules commencing above 48·5°C. may show fixation of starch; examples of timbers normally dried at these higher schedules are European walnut, iroko, agba and obeche. On the other hand, high temperatures might affect the starch grains in such a way as to render the sapwood unsuitable for *Lyctus* attack. Harris also pointed out that the speed of kiln drying reduces the period of exposure to risk of *Lyctus* attack.

Agencies such as defoliating insects, fire damage or pruning, that produce severe defoliation but permit subsequent vigorous crown regeneration will result in starch depletion during the latter stage. Workers in New South Wales are investigating the possibilities of achieving starch depletion resulting from defoliation artificially produced by the use of suitable chemicals (Bamber *et al.*, 1960).

Steaming starchy oak sapwood rendered it unsuitable for normal larval development (Fisher, 1952) and a similar result has been obtained with white ash (Synder, 1938).

Concurrently with these investigations, the possibilities of protection by the use of preservatives have been studied. Christian (1939, 1940) concluded that borax, amongst water soluble materials tested, and pentachlorophenol, amongst oil soluble materials, were the most effective substances when employed as ten-second dips. Although sodium fluosilicate was the most toxic of a number of inorganic chemicals tested by Cummins and Wilson (1936), boron in various forms has been accepted in Australia and New Zealand as the most practicable of these substances. Maintenance of a concentration gradient in green timber is the basis of impregnation by diffusion of boric acid, which has proved more diffusible than borax (Harrow, 1951). The loadings obtained by Harrow depended on the solution concentration, time of treatment and wood angle; the last may cause low core loadings in quarter-sawn boards (Harrow, 1952a). The post immersion storage period under restricted drying conditions depends on the thickness of the boards but where a long period is required the advantage over treatment by pressure impregnation of only one drying is lost (Harrow, 1952b). The diffusion method of treatment with boron compounds is suitable for green timbers for structural purposes, and in some species better penetration may be achieved than by treatment under pressure; it may be used also for green veneers (Gregory, 1942; Tamblyn, 1949).

In the United Kingdom the *Lyctus* problem is mainly one of providing temporary protection to sawn timber or partly manufactured articles until they receive a protective finish, sealing the pores of the wood and thus preventing egg-laying. In consequence earlier work at this Laboratory on dip treatments using water or oil soluble chemicals which had not proved entirely satisfactory was discontinued with the appearance of contact insecticides offering the possibility of a simple, cheap and effective method of giving such temporary protection. My colleague, Miss Taylor (1960a), found application of BHC and DDT by an insecticidal fog machine failed to give sufficient coverage to prevent attack, but spray treatments applied to the sapwood edges of sawn logs with 0·5 per cent. γ isomer of BHC provided protection for one season. European oak was, however, protected for three years by a ten-second dip in emulsions of DDT (2 and 1%), BHC (1 and 0·5% γ isomer) or dieldrin (1·0 and 0·5%). It is, therefore, suggested that when stocks of *Lyctus* susceptible hardwoods are to be held in store for more than one year, dipping treatments are to be preferred to spraying. Recommendations incorporating these findings have been published in the form of a leaflet suitable for use in the timber trade (For. Prod. Res. Lab., 1960).

In India similar recommendations for spray treatments of stored plywood panels bound together into bundles have been made by Chatterjee (1953). In the United States of America dipping treatments with DDT or BHC have been recommended for green lumber and these substances or toxaphene or chlordane applied as a three-minute dip for dry hardwood products have been found to give protection for five or more years (Johnston *et al.*, 1955).

Studies on the effect of adding preservatives to the glue line during the manufacture of plywood containing susceptible veneers have been conducted in Australia (Tamblyn and Gordon, 1950). Amongst the substances tested, DDT and BHC gave the best results and may be mixed with cold-setting urea-formaldehyde or casein glue. BHC has given protection for twelve years and the experiment is continuing but some attack occurred after five years in plywood manufactured with DDT in the glue line (C.S.I.R.O., 1953, 1959, Div. For. Prod., unpublished resumés of work). It is unfortunate that BHC is not stable in alkalis such as phenolformaldehyde glues; DDT and dieldrin may be used in these circumstances. Published data on the effectiveness of dieldrin used in this way are lacking.

Control

In sawn timber where infestation is severe, sapwood must be eliminated; where this is unnecessary kiln sterilisation provides an effective cure but offers no protection against subsequent reinfestation. This method, with certain reservations, is also applicable to manufactured articles. Early work on kiln sterilisation was summarised by Parkin (1937b) who gave fresh data on suitable combinations of temperature, humidity and times of treatments required in relation to the thickness of the timber. Recommendations (based on Parkin's results) suitable for commercial practice have been made in Forest Products Research Leaflet No. 13 (1957), but these schedules may not be directly applicable to Bostrychid powder-post beetles (Rep. For. Prod. Res. Board, 1952).

Fumigation is likely to be effective where this method of treatment is applicable, but the special precautions needed and consequent cost limit its value. Suitable concentrations and times of treatment required in chambers or under gas-proof tarpaulins are given by Johnston *et al.* (1955).

The use of liquid insecticides is usually confined to instances where kiln sterilisation or fumigation are not applicable and replacement is unnecessary. In manufactured articles or flooring, surface applications of insecticide are of limited value unless the surface finish is previously removed. The solvent may dissolve the bitumen in which flooring blocks are embedded, thus loosening or staining the blocks (Tooke, 1953). Parquet and strip floors present a peculiarly difficult remedial problem and replacement of the affected parts is usually the safest measure.

So much for the traditional methods of artificial control, a brief account of investigations on the possibility of developing newer methods may be of interest. Gamma radiation has been tested on the larvae and adults of this species amongst others (Bletchly, 1958; Bletchly and Fisher, 1957). Since it was found that very high dosages would be required to produce a rapid larval mortality, studies were concentrated on sub-lethal dosages and showed that larval development was arrested by irradiation of infested wood at 8,000 roentgens and that where adults of both sexes were irradiated at this dosage, they failed to lay fertile eggs. On account of the hazards involved in using such dosages, combined with initial costs, and for technical reasons, it appears unlikely that there will be any immediate application of the data obtained.

The use of infra-red radiation has also been considered and Pence (1956) has described a suitable unit for use by pest control operators. Damage to surface finishes may result. Data obtained at this Laboratory have not been satisfactory, since although ⅜ inch obeche plywood infested by *Lyctus* was sterilised when a temperature of 55°C. was obtained on the under-surface of the material, a similar treatment applied to infested ¾ inch oak floor blocks failed to destroy all the larvae (For. Prod. Res. Lab., 1960).

Investigations on the use of high frequency heating have not shown promise. Higher temperatures (65°C.) were required to produce complete larval mortality compared with kiln sterilisation (46°C. to 52°C.) and hoped-for differential heating effects in the larvae were not obtained (Thomas and White, 1959).

The possibilities of biological control have never been fully investigated and although in theory it seems unlikely this method alone could be effective, yet following the use of artificial control measures it might be of value towards eliminating a residual *Lyctus* population. Predators and parasites of *Lyctus* have been recorded by Beeson (1926), Browne (1938), Christian (1941), Fisher (1944), Froggatt (1927), Gahan (1954), Kojima (1932), Snyder (1938) and Vrydagh (1946).

Conclusions

This brief summary of some aspects of *Lyctus* powder-post beetle infestation, its prevention and control, is intended to draw attention not merely to the progress made in fundamental and applied studies at the Forest Products Research Laboratory and elsewhere, but also to indicate some of the outstanding problems which remain to be solved.

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Discussion

Mr. D. J. Colwill remarked that some of Mr. Jones' data indicated that, whereas formulations of γ BHC were initially effective against ambrosia beetles and then gradually lost their activity with increased age, formulations of aldrin and endrin were initially of little value but by the end of about ten weeks their activity was parallel with that of γ BHC, and he enquired whether there was any explanation of that phenomenon. Mr. Tecwyn Jones said that he had no further information available, but it might be that the aldrin and endrin were improved by formulations such as had earlier been discussed by Dr. Hadaway, so that surface adhesion and penetration were affected. BHC stayed steady, so a direct comparison was not possible, and the formulations used in those particular experiments were also not directly comparable, as some were paints and others aqueous solutions.

Dr. F. S. Downing enquired how long the ambrosia beetles remained on the log surface before boring in, and whether they spent some time in first searching for a suitable site, as he was interested in the reasons for the known differences in action of BHC and aldrin and wondered whether their relative contact and ingestive effects were responsible. The speaker replied that he would favour the contact effect of an insecticide, for a beetle alighted on a log after briefly flying about it, and then spent between five minutes and half-an-hour in searching for a boring site, whereas the amount of stomach ingestion was small.

The Chairman asked whether it was correct that painting or varnishing a wooden surface prevented oviposition by *Lyctus* by occluding the pores of the wood. Mr. Bletchly agreed that it was so, and was usually sufficient protection under normal circumstances provided that the wood was not already infested. Work by Harris had, however, shown that if *Lyctus* was confined to such treated surfaces without alternatives being available, then it would perforate some finishes in order to oviposit.

Mr. Tecwyn Jones was interested to learn that *Lyctus* had been recorded from *Pinus canariensis*, for in East Africa the planting of pines had been included in the programme and pine timber would be used in future building in that area. He asked whether the attack had been successful, and whether there were any other records of Lyctids in pines or other softwoods. Mr. Bletchly answered that the attack had been successful, but he added that *P. canariensis* was one of the few softwoods with sufficient reserves of starch to be suitable for *Lyctus*. He thought that softwood infestation by *Lyctus* was unlikely to become a major problem.

Mr. T. Greaves stated that compulsory legislation had been introduced in Australia to protect the consumer against the infestation of furniture by *Lyctus*. An effective treatment developed by the New South Wales Forestry Commission consisted of using dieldrin dissolved in kerosene with an added penetrant. Mr. Bletchly differentiated between the problem in Australia and the United Kingdom, for in Australia more hardwood is used, and in Britain most furniture is given a protective finish by the manufacturer.

Mr. L. P. Lefkovitch enquired whether it was known if the sterility of *Lyctus* adults caused by exposure to sub-lethal doses of γ-rays was permanent, or whether fertility was later regained, as was believed to be the case with *Tribolium*. Mr. Bletchly replied that sterility has been recorded for up to eighty-four days without recovery in *Lyctus*, and that was the extent of the adult life. In the case of *Xestobium rufovillosum* Deg., which overwintered in the adult stage, γ-irradiation had been very successful when applied to young and hibernated adults and no suggestion of the recovery of fertility had been noticed in those experiments.

DISCUSSION ON TERMITE CONTROL IN AFFORESTATION PROJECTS AND CONSTRUCTIONAL TIMBERS

Chairman: Mr. D. Rhind, O.B.E., *Secretary for Colonial Agricultural Research, Colonial Office*

The Chairman said that it was scarcely necessary to introduce Mr. Harris, the first speaker, who was Officer-in-Charge of the Termite Research Unit. The second speaker, Mr. W. A. Sands, was also a member of the Unit, and had recently completed an assignment in Nigeria.

Observations on the Termites which Damage Constructional Timbers

By Mr. W. V. Harris
Officer-in-Charge, Colonial Termite Research Unit

While there appears to have been little increase in general appreciation of the amount of damage which termites do to agricultural crops and growing trees, there is no doubt about the recent improvement in what might be called a " willingness to recognise " the widespread activities of termites in constructional timbers. This increased interest in the age-old question of termite attack in buildings is due in great measure to two of the newer developments of Western Civilisation—hire purchase and the chemical industry. People who advance money for house purchase or factory construction are far more concerned about the security of their loan than is the tenant, especially if he built his house with his own hands, or the Government departments who have been responsible for much of the so-called permanent buildings in tropical countries. The chemical manufacturer and the pest control operator, who is his main link with the consumer, have between them vast resources of publicity not, until recent years, directed towards the termite control field. It is not unlikely, therefore, that official entomologists will find themselves being asked for their opinions on proposals for the protection of buildings against termites, or for the elimination of infestations, with an urgency that has hitherto been absent, due in no small part to the large sums of money involved. Some observations on the entomological aspects of the problem are discussed here.

A recent survey of the literature and of the records of the Termite Research Unit (Harris, 1961) has shown that 109 species of termites have been identified as damaging constructional timbers in various parts of the world. They are distributed among five of the six families which together constitute the order Isoptera as follows: Mastotermitidae, 1; Kalotermitidae, 20; Termopsidae, 2; Rhinotermitidae, 43 and Termitidae, 43. The Hodotermitidae are not implicated since they are a small family of harvesting termites feeding only on dry grasses in the open grasslands of Africa and the Middle East.

The family Mastotermitidae is composed of a single living species, *Mastotermes darwiniensis* Froggatt, restricted to tropical north Australia. It is a serious pest within the limits of its distribution, but in view of these limits being restricted and because it is another of those Australian animals which it is not easy to fit into a simple classification, it can be left out of this general survey.

KALOTERMITIDAE " dry-wood termite "	TERMOPSIDAE " damp-wood termite "	RHINOTERMITIDAE " moist-wood termite "	TERMITIDAE " Subterranean termite "
with intestinal protozoa			no protozoa nest in ground
no connection with the ground; nest within dry wood.	usually some connection with the ground; nest in damp wood.		
Kalotermes *Cryptotermes*	*Zootermopsis* *Stolotermes*	*Psammotermes* *Heterotermes* *Reticulitermes* *Coptotermes*	*Amitermes* *Microcerotermes* *Macrotermes* *Odontotermes* *Microtermes* *Nasutitermes*

Four widely distributed families of termites remain to be considered (see Table), the Kalotermitidae, the Termopsidae, the Rhinotermitidae and Termitidae. There are striking differences both in the individual termite and the society to which it belongs in each of these families which make their determination of primary importance to successful and economic control.

The Kalotermitidae are dry-wood termites whose life is passed within the wood on which they feed. Under natural conditions they are found in dead branches, snags and old wounds on standing trees, but some twenty species belonging mainly to two genera—*Kalotermes* and *Cryptotermes*—have found satisfactory alternative niches in the timber-work of buildings. Dry-wood termites depend on intestinal protozoa for the digestion of cellulose, and if anything happens to these protozoa the termite hosts die of starvation. New colonies arise when winged adult termites in pairs alight on a suitable piece of wood, or when a part of an old colony becomes isolated from the main body in a part of the intricate gallery system. At no time during the life of the individual or the community is contact with the ground essential.

The Termopsidae are a small family of damp-wood termites which, like the Kalotermitidae, depend on intestinal protozoa and live in galleries in wood, but in this case the wood must be damp and rotten as one finds in fallen logs on the forest floor or in wounds on standing timber where moisture can accumulate. Two genera only have been recorded from buildings, *Zootermopsis* in western North America and *Stolotermes* in New Zealand. This family appears to have been pushed to the outer limits of termite distribution by the more highly developed Rhinotermitidae, which resembles them in depending on cellulose digesting protozoa but has a central nest system from which workers go out in search of food. While the nest itself requires moist wood as its site, dry wood can be used as a food supply. These two families differ from the dry-wood termites in that the need for damp wood usually means some connection with the ground as a source of moisture. The Rhinotermitid genera *Coptotermes*, *Heterotermes* and *Reticulitermes* have all been found in buildings without direct connection with the soil however, in cases where timber has been kept damp by leaking water pipes, and in the case of *Coptotermes* in wooden ships. Forty-three species of Rhinotermitidae are recorded from buildings.

Lastly, there is the large family of the Termitidae whose members exhibit a wide range of shape and behaviour though they are uniform in having no intestinal protozoa to digest cellulose for them, in having fixed nests usually in or on the ground, and even when they make their nests on the trunks of trees or poles supporting buildings they maintain a close connection with the soil, and finally they collect dry sound timber for food as well as woody matter in all stages of decay. Of this family forty-three species are recorded from buildings, belonging to such genera as *Amitermes, Microcerotermes, Macrotermes, Odontotermes, Microtermes* and *Nasutitermes*.

There are three main ways of preventing termite attack on building timbers—wood preservation, site poisoning and constructional measures. In any consideration of which of these, alone or in association, will provide adequate protection at the lowest cost the first point to be dealt with must surely be the identity of the termites present, because of the important differences which have already been described in the families known to attack buildings. This is no original idea but it is insufficiently appreciated, even among those who might be expected to know better, that family differences in the Isoptera have direct bearing on control.

New chemicals and new formulations of well established chemicals are continually being offered for the protection of timber against termite attack. Any evaluation of experimental evidence offered in support of claims in this field must be made in the light of knowledge of the particular termites involved in the tests. While this may not be so essential with insecticides of recognised general killing powers, such as arsenicals and phenols, it becomes important when they are more selective. The division of termites into those with intestinal protozoa and those without is one of the main factors, for it is possible to kill off the protozoa without immediate damage to the host though leading to its death ultimately from starvation. As an example there are the important family differences in toleration of boron preservatives demonstrated by Gay and his colleagues in Australia (1958). They found that the genus *Coptotermes*—Rhinotermitidae—reacted strongly to boric acid concentrations of from 0·05 to 0·56 per cent. according to species, while *Nasutitermes exitiosus* (Hill)—Termitidae—was able to tolerate concentrations as high as 1·09 per cent. without significant effect. This, they suggest, is due to the high sensitivity of the protozoa on which *Coptotermes* depends, as compared with the termites themselves.

The problem is not always so simple and clear cut, for in the same paper Gay records the higher tolerance of " Tanalith U " shown by *Coptotermes acinaciformis* (Froggatt) as compared with *C. lacteus* (Froggatt) although observations on the feeding habits of these two species suggest that *acinaciformis* is a much more voracious feeder and thus likely to ingest larger amounts of the preservative.

The use of barriers to prevent termites gaining access to buildings from the soil is of no value in the case of the dry-wood termites who have no connection with the ground, but of great practical value with all other kinds of termites. Since there are few if any localities where dry-wood termites are not accompanied by ground-dwelling species, there is always a case for the incorporation of barriers in new constructions, especially as ground-dwelling termites attack sooner and with greater intensity than the dry-wood termites. In those localities where dry-wood termites do occur, the long-term policy for complete freedom from attack must include the impregnation of all timber in the building, but this would not be essential if the building is of a more temporary nature. The practical weakness of barriers, whether chemical soil poisons or mechanical in nature, lies in the difficulty of ensuring that they have been constructed with absolute thoroughness. Hence the desirability of employing more than one method at the same time.

The division of the termite families into those with no ground contacts and those with obligatory contacts, the Kalotermitidae on the one hand and the remainder on the other, is like so many divisions in the biological world subject to important exceptions. The genus *Coptotermes*, one of the moist-wood termites with intestinal protozoa and static nests in damp wood in the ground, is one of the most injurious genera, especially in the Far East and Australia. It is able to nest satisfactorily in timber that is kept sufficiently moist by other means than by contact with the ground. Such situations can be located by pairs of winged adults, without the colony having to be started off underground and then moved up later, with the result that wooden boats may become infested while afloat. One cannot be absolutely certain how often the infestation of buildings occurs in a similar way, but in some cases it is a reasonable assumption. This is a matter of practical interest in controlling infestations of *Coptotermes* since nests are possible in suitable situations high above the ground which would be quite unlike anything the Termitidae ever achieve.

The design of structural barriers is influenced by the occurrence of mound building termites, especially species of *Macrotermes* and *Odontotermes* in Africa and tropical Asia. Rapidly constructed mounds may bridge the gap or projecting shield of a constructional barrier which would be quite adequate in localities without these genera. This does not mean that such barriers are wrong in principle, but only that the design is at fault.

In conclusion, some generalisations are offered on the distribution of termites which are serious pests of buildings as a guide to the kinds which should be anticipated in those areas where detailed surveys have yet to be made.

Among the dry-wood termites the genus *Cryptotermes* is by far the most injurious. All the nine economic species are tropical, their place in cooler climates being taken, though to a lesser degree, by *Kalotermes*. Man has distributed the destructive *Cryptotermes* to such an extent that, as with many economic plants, their country of origin is now in doubt. They are apparently restricted to islands and to the coastal belts of the continents, a matter of some importance when considering minimum standards of termite precautions in buildings far removed from the sea.

The injurious moist-wood termites of the family Rhinotermitidae belong to four genera. *Coptotermes*, with twenty species, is very active in south-east Asia and Australia, with minor occurrences on the East and West African coasts and in the Caribbean. *Heterotermes*, with eight species, takes its place in Central and South America, and *Reticulitermes*, also with eight species, spreads right across the more southerly parts of the northern Temperate zone. The small genus, *Psammotermes*—the sand termite—is restricted to the arid regions of Africa and Arabia, causing little damage only because of the scarcity of buildings there to attack.

The family Termitidae provides three groups of injurious species. The fungus-growing termites belonging to *Odontotermes*, *Microtermes* and *Macrotermes* are the main cause of damage in Africa south of the Sahara, in the Indian sub-continent, and in south-east Asia as far north as Formosa and west to Celebes. The *Nasutitermes*, with its peculiar nasute soldiers and a tendency towards arboreal nests, takes its place in the warmer parts of Australia, and in Central America and the north of South America. *Microcerotermes*, which with the related *Amitermes* provides a number of pests of minor status in many parts of the tropics, is a major pest in Arabia and the Persian Gulf area—possibly in the absence of serious competition from other genera.

Knowledge of the termite fauna of a particular locality does enable a choice to be made of the precautions which may be adopted to reduce the risk of termite infestation of building timbers. The successful control of existing infestations depends greatly on local knowledge of the particular species, but recognition of the families concerned will be of value in deciding general policy.

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Termite Control in West African Afforestation

By MR. W. A. SANDS
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At the sixth Commonwealth Entomological Conference in 1954 it was recommended that an entomologist should be appointed to the Termite Research Unit specifically to study methods of control of termites as pests in agriculture and forestry. In practice it has been possible to combine these aspects with the other activities of the Unit, and the results obtained in Northern Nigeria on the protection of young trees are discussed here. This work was carried out in close co-operation with the Forest Department of Northern Nigeria during the four years in which the Unit has been in operation in West Africa, when the writer was based on the Regional Research Station of the Ministry of Agriculture, Northern Nigeria, at Samaru, near Zaria.

Termite damage to growing plantation trees is widespread in West Africa. The most frequently attacked are the valuable quick growing eucalyptus trees, but a number of others also suffer in some areas, such as Neem, *Dalbergia*, *Cassia* and Flamboyant in Nigeria, and teak and *Dalbergia* in Northern Ghana. Similar types of damage occur to tree crops such as Cocoa and Rubber in the more humid areas of the south. In some areas the planting of eucalyptus has been entirely abandoned, since over a period of a few years, plantations have been entirely destroyed.

The most important termites damaging living trees in West Africa (and indeed the whole of Africa) are those belonging to the family Termitidae, subfamily Macrotermitinae. These are commonly referred to as the fungus-growing termites, because of their habit of constructing within their nests sponge-like masses of mixed vegetable and mineral material which support basidiomycete fungi of the genus *Termitomyces*. Attacks by members of other subfamilies do occur, for example: the greatest damage to seedling teak in Northern Ghana is done by *Amitermes evuncifer* Silv., an extremely common and widely distributed member of the Amitermitinae. Members of other families such as *Neotermes aburiensis* Sjöstedt (Kalotermitidae) and *Coptotermes* sp. (Rhinotermitidae) do occasionally cause some damage to trees in the forest areas, but they are not of great economic importance in this respect in West Africa.

The larger species of Macrotermitinae cause the most rapid damage. Two species of *Macrotermes* are common over much of West Africa, namely, *M. natalensis* (Haviland) which builds the tall " cathedral " mounds in the savannah, and *M. bellicosus* (Smeathman) which produces a mound with a less complex internal structure than that of *natalensis*. Together these two species constitute the greatest threat to young plantations.

Other related species, which are nearly as widespread, and only slightly less rapidly lethal to young trees are *Pseudacanthotermes militaris* (Hagen) and several species of *Odontotermes*. The smaller genera, such as *Microtermes* and *Ancistrotermes*, are slower to cause large scale damage, and seldom kill trees after one year from planting.

Because both species of *Macrotermes* build conspicuous mounds in most soil conditions, their colonies are comparatively easy to recognise and destroy. Species of *Odontotermes* and *Pseudacanthotermes* often build low, wide mounds covered with trees, but these genera, and also *Macrotermes* and *Ancistrotermes* commonly live in rather diffuse entirely subterranean nests, which make it impossible to seek them out for individual destruction. Sampling of the upper three feet of soil in Northern Nigeria has indicated that *Pseudacanthotermes* and *Microtermes* are almost ubiquitous in the soil of the open guinean savannah woodland.

The larger species usually commence their attack below ground level, in the upper six to nine inches of the soil. The tap root is ring-barked, and damage is then often extended for some distance above the soil. Following ring-barking the wood is attacked, and the tree is frequently felled by the termites. Damage by the smaller species commences with the penetration of the tap root, and is continued by hollowing out from below. Mud runways may be built up the side of more mature trees. The attack of the smaller species more often leads to distortion and stunting rather than death to the tree, or is a secondary feature to a primary attack by the larger species.

When the Termite Research Unit began its activities in Northern Nigeria in November 1956, the standard technique for the establishment of eucalyptus plantations was by means of root pruned striplings four to eight feet tall. This drastic treatment predisposed the young trees to suffer termite damage, particularly since the forest labourers habitually trimmed the tap root with a cutlass to fit the planting hole, which frequently was not dug to a sufficient depth. Since that time, methods have changed, and now pots of various types are used in the nurseries with correspondingly greater possibilities of successful control methods being applied.

The first experiments in control were necessarily superimposed on the old method of planting. The weather conditions at planting out time in early July prevented the use of dust formulations, but provided ample water for the dilution of dieldrin emulsifiable concentrate. This was used in order to obtain the maximum possible dispersion of the insecticide through the wet soil in the planting holes. The diluted insecticide was applied with watering cans, a method which proved to be very slow, and was rejected for general use by the Forest department as being uneconomic due to the increased labour costs. It did achieve a measure of success however, subsequent counts of surviving trees showing 58 per cent. mean survival in treated plots as compared with 17 per cent. untreated controls, two-and-a-half years after planting out.

Since the introduction of pot planting techniques, further methods of insecticidal treatment have become possible. The manner of attack by termites, confined, with rare exceptions, to the top nine inches of soil only, means that a poisoned pot of this depth gives a considerable degree of protection. The first method to be introduced was that of treating seedlings already established in pots with dieldrin emulsifiable concentrate diluted and applied through the nursery watering system. Care was needed to avoid phytotoxic effects due to the oil base of the emulsion, and the insecticide was therefore applied as four dilute doses over a period of some weeks before planting out.

Soil from the upper and lower halves of sample pots was tested against *Trinervitermes ebenerianus* Sjöstedt, a species of termite common in the vicinity. It was found to be toxic at all levels, with a tendency to be slightly more toxic in the upper half. Pots treated in this way were planted out in July 1958 in an area where eucalyptus planting had long been abandoned, and even *Cassia* had failed to grow satisfactorily.

Mortality due to termites in the first eighteen months was virtually non-existent, less than 1 per cent. Occasional damage occurred where a pot of insufficient depth had left an inadequate collar of poisoned soil round the plant, allowing access to the lower part of the tap root by *M. natalensis.*

In July 1959 the use of seedlings in polythene bag pots was begun. The soil in the pots was pre-treated with dieldrin 2 per cent. dust, an experiment being laid out to compare the efficacy of differing doses of insecticide, and to compare the dust with the emulsion method of treatment. The dust treatment was carried out in a mixing churn to ensure the best possible dispersion of the insecticide.

A sample of soil from each mix was again tested against *T. ebenerianus* in the laboratory and showed very good dispersion and uniformity of the insecticide. Among 1,000 *Eucalyptus multiflora* planted out only two cases of termite attack occurred up to the time of writing, and these only where a cap of unpoisoned soil had been washed over a too deeply planted pot by the heavy rains. It is too early to judge the success of this experiment but the results so far give promise of achieving control.

It is appropriate to include reference to an experiment which indicates the persistence which may be expected for some organic insecticides in tropical savannah soil at approximately forty inch rainfall: aldrin, dieldrin and BHC were exposed to weathering in open plots at Samaru for three years. Doses of aldrin and dieldrin equivalent to 2 lb. per six-inch deep acre persisted in effective amounts throughout this time, as was shown by testing against *T. ebenerianus* at intervals of several months.

All the treatments described above were local applications around the tree requiring protection. In the case of attacks on seedlings or saplings in nursery beds, a general application to the soil was recommended in a number of cases, notably that of the attack on young teak by *Amitermes evuncifer* in Northern Ghana. However, the widespread use of general applications of insecticides to tropical soils may prove to be undesirable. It would in any event, be too expensive for use by the forest departments and native authorities for whom this work was carried out, but in addition, the effect of the removal of termites from tropical soils requires further study before the possible hazards of complete eradication are undertaken. Water penetration is already poor on soils unbroken by mechanical cultivation in Northern Nigeria. There is at least a possibility that as a result of the prevention of the tunnelling activities of termites it might become almost non-existent, resulting in more serious sheet erosion and infertility. Observations at Samaru suggested that termites had been eradicated from a considerable area by continued mechanical cultivation alone. In laboratory experiments with *T. ebenerianus* a concentration of 0·0018 parts per million of dieldrin in filter paper proved rapidly lethal. This is lower by a factor of hundreds than the dosages normally used and suggests that the large scale application of insecticides to tropical soils should be approached with caution.

Discussion

Mr. E. O. Pearson commented on the termite invasion of planted seedlings, which Mr. Sands had said was prevented by the use of soil treated with an insecticide and filled into pots, and wondered whether pots alone would provide protection. Mr. Sands had no actual information on that point, but said that if the pots were short, damaged, or became capped with the surrounding soil in heavy rains, then attack occurred. In answer to a question by Dr. R. M. Dobson, he said that the expression " pot " covered any sort of container, from a beer can to more orthodox varieties. Polythene bags were found to be best, and they could be planted and left to disintegrate.

Mr. C. H. Cronin asked about the dosage rate of insecticides used in protecting eucalyptus seedlings before they were planted out. Mr. Sands replied that seedlings were treated with 4–5 oz. of emulsion concentrate per 100 gal. per 1,000 pots, and that potting soil was treated with dieldrin 2 per cent. dust at 5–10 oz. per cu. yd., of which the lower rate was approximately equal to 5 lb. per 6-in. acre. Tests had shown that dieldrin applied at the rate of 2 oz. per cu. yd. [*i.e.*, 2 lb. per 6-in. acre] was still present in the soil after two years.

Mr. T. Bosman wondered whether Mr. Sands had been dealing with a population saturated with regard to its food supply, and thence whether the provision of alternative food, such as the placing of a mulch, would have the effect of drawing the termites away from the seedling trees, but Mr. Sands said that not enough was known ecologically about the West African termites to be able to tell if a saturated population was being dealt with. Both he and Mr. T. Greaves thought that non-living food material would not be sought by the termites, and dead trees would in any case not be tolerated in stands of eucalyptus.

Mr. J. D. Bletchly asked whether soil poisons provided an effective alternative to barriers in the protection of buildings from termites, especially with regard to permanence. Mr. Harris replied that poisoning was of the utmost value when an attack suddenly developed, and that it would at least persist long enough to protect a building during the period of its mortgage. The choice of suitable chemicals was, however, limited, for arsenic had a bad name and pentachlorophenol had not been tested for a sufficient period to know the full story of its persistence. Some of the chlorinated hydrocarbon insecticides had so far lasted for four to five years when applied beneath concrete with polythene film sheeting.

Mr. T. Greaves showed a series of slides of Australian termites with the following comments on the various species.

The greatest loss of timber by insects in Australian hardwood forests is by termites; however, the attack usually occurs in large trees and termites rarely set up a new colony in a tree of less than 12 in. diameter. In most other parts of the world termite attack on living trees is often in the seedling and sapling stage.

Surveys have shown that three species of termites, *Porotermes adamsoni* Froggatt, *Coptotermes acinaciformis* Froggatt and *C. frenchi* Hill cause most of the loss of timber.

During the last four years investigations have included studies of territory (*i.e.*, gallery), of population and of temperature of colonies in relation to their immediate environment. A general paper on the work has been published in Vol. 23 of Australian Forestry.

At the outset it was planned to obtain some measure of the economic loss caused by termites, but this was not possible, as foresters were more concerned with the losses in timber as girders, poles, etc., than the much greater loss through the logs rejected in the forest and left to rot. Recently, a detailed examination of several thousand logs, felled in a number of forests, has provided data on which the loss in revenue can be assessed. This phase of the work would not be possible without the generous help of the foresters.

C. acinaciformis is by far the most serious pest species, it is most common in coastal forests in tropical and sub-tropical Australia, and also in the warmer inland plains where moisture is available. *C. frenchi* is a smaller species and can tolerate cooler and drier conditions than *C. acinaciformis*; it is commonly found at elevations between 1,500 and 3,500 feet. *P. adamsoni* is a pest of alpine forests and the loss by this species is greatest in the high altitude areas of Victoria and New South Wales. Losses of more than 50 per cent. of the logs occur in some forest compartments. *Porotermes* attack on trees is limited to the tree attacked, it does not spread to other trees, but can survive in logs after the tree is felled.

Damage by this species can be prevented by a sound regeneration programme, including the removal of large trees, and good silvicultural treatment of younger stock; however, the attack by the two *Coptotermes* species persist even in highly developed eucalyptus forests.

Territory studies, involving the excavation of galleries, have shown that *C. acinaciformis* can *initiate attack* on other living trees from a central colony, established in a living tree, dead stump or mounds. The entry into the secondary living tree is by direct attack, *i.e.*, not through damaged or decayed wood. Trees can be attacked for a distance of 150 feet from the central tree, and, in one colony system studied, the attack radiated from a central colony situated in a large red ironbark, to sixteen other living trees as well as logs and stumps in 0·4 acre of forest.

Under some conditions termite colonies are very competitive for trees and this competition is being studied.

Methods were developed to study the populations of colonies of *Coptotermes* in trees; over 700,000 termites were obtained from a colony of *C. acinaciformis*, and over 400,000 from a colony of *C. frenchi*; these were only portions of the total colony's populations, as the vibration caused by felling and splitting trees, together with unfavourable weather conditions, resulted in many termites being left in the tree and the surrounding soil.

The phase of the work that can be illustrated in detail, in the time available, is that of the temperature studies of colonies. Detailed studies of colonies of *C. frenchi* and *C. acinaciformis* were made *in situ* by means of thermocouples installed in infested trees. It was found that the nursery temperature, *i.e.*, the temperature of that part of a tree that is infested, was as much as 22°C. higher than the temperature of a sound tree and that the temperature was markedly lower above and below the nursery. Studies of the lateral spread of temperature have shown that the tree provides a wonderful insulation for the nursery and the high temperature of the nursery did not markedly affect the wood for more than 9 in. There was a marked fluctuation of temperature under the bark on sunny days.

Continuous records of temperature were taken over twenty-four hour periods, at varying seasons of the year. These showed that there was little variation in the centre of large trees over a twenty-four hour period, but there were some interesting fluctuations in nursery temperature in *C. acinaciformis* colonies during the winter.

The temperature of the nursery area in a vital colony is often as high as 95°C. and temperature readings were regularly used to select vital colonies for research. When thermocouples were installed in trees it was possible to study the temperature trend when a tree was jarred by violent knocking, as when in felling. The temperature loss suggests that the bulk of the colony vacates the nursery area during severe jarring. Similar readings of the temperature of colonies treated with arsenic trioxide have shown that following the application of the arsenic there was an immediate decline in temperature followed in a few days, by a rapid increase in temperature when the dead termites became fermented.

The aim of these investigations is to study the termites in detail so as to obtain background information on which to base methods of control.

DISCUSSION ON THE UTILISATION OF PATHOGENIC ORGANISMS IN THE CONTROL OF INSECT PESTS

Chairman: PROFESSOR G. C. VARLEY, *Hope Department of Entomology, University of Oxford*

The CHAIRMAN said that the subject of this session was of absorbing interest, and was one to which had been given an increasing amount of attention within the last few years. The first speaker, Dr. Kenneth Smith, would be dealing with the general nature of viruses known to attack insects, and no one was better equipped to do so. The second speaker, Dr. Ossowski, would be dealing with a special case of the practical use of an insect pathogen in the field.

Some Factors in the Use of Pathogens in Biological Control with Special Reference to Viruses

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The word pathogen in this context refers specifically to bacteria and viruses, because these are the only two which have been used at all extensively in the control of insect pests.

Since my personal experience of biological control has been confined to the use of viruses, I can make but limited reference to the work done so far on control of insects by pathogenic bacteria. Of these the most promising, or at least the most advertised, is *Bacillus thuringiensis*; there are two salient facts about this micro-organism, one is its apparent applicability to a wide range of pests and the other is its mode of action.

Infection appears to be confined to caterpillars but these include the cabbage whites, *Pieris brassicae* (L.) and *P. rapae* (L.); the gipsy moth, *Lymantria dispar* (L.); the codling moth, *Cydia pomonella* (L.), and various larvae attacking forest trees. The mode of action of *B. thuringiensis* is rather peculiar; it is one of the crystal-forming bacteria and the spores contain a spindle-shaped crystal which is extremely toxic to the gut of the larva. This apparently enables the spores to infect the new host as otherwise they would pass through the caterpillar without causing infection. This mode of action has suggested the term " microbial or living insecticide." Another example of bacterial control is the successful application to the soil of *Bacillus popilliae* causing the " milky disease " of the larva of the Japanese beetle.

Before we discuss the application of viruses in the control of insects it will be useful to give a short description of these viruses because they are not all equally efficacious in this respect. So far as we know at present insect viruses fall into three main groups, the polyhedral viruses or *polyhedroses*, the granular viruses or *granuloses* and the *free viruses* without any intracellular inclusions. The polyhedroses are so-called because the tissues of infected insects are filled with polyhedral crystals; these crystals, which are not virus crystals, are protein in nature and contain the virus particles occluded within. In the granuloses the tissues are filled with minute granules just at the limit of resolution of the optical microscope; these granules are also very small protein crystals and contain, as a rule, one virus rod.

The polyhedroses consist of two types, and this is important in considering their suitability for use in control. In the *nuclear polyhedroses*, the virus multiplies in the nucleus of the cells of the fatbody, blood, skin and tracheae and is rod-shaped. In the *cytoplasmic polyhedroses* the virus multiplies in the cytoplasm of the gut cells and is near-spherical in shape.

The diseases caused by these two types of viruses are different and this too is important from the point of view of control. In the disease caused by the nuclear virus, the skin of the caterpillar is attacked whilst the body contents become liquefied. The practical result of this is that the skin ruptures and the liquid contents with millions of polyhedra are spread far and wide over the plant. With the cytoplasmic disease the skin is not attacked and there is a tendency for the body to be desiccated; in consequence the dissemination of the polyhedra is less efficient though this is partly compensated for by the fact that some polyhedra are voided with the faeces. At this point it should be emphasised that the polyhedra play an important part in the dissemination of the virus; they are very resistant to environmental conditions and retain the virus in a viable state for long periods even for some years. The main method of spread is by the ingestion of the polyhedra when the larvae eat contaminated leaves, but there is also the very important trans-ovarial transmission which we shall discuss later.

It may be convenient if we discuss separately some of the various factors governing the successful use of pathogens in biological control.

Accessibility of Insects

Since both the spores of *B. thuringiensis* and the virus act like a stomach poison insecticide in the sense that they must be ingested, the availability of the insects to be controlled is an important point. Insects which feed exposed and gregariously on the foliage are obviously an easier target than those which are hidden in the bud or are soil-living.

From the point of view of control by viruses the ideal subject would be the larvae of

Pieris brassicae, the large white butterfly and other Pierids. They fulfil all the conditions of good accessibility, feeding openly and gregariously on low-growing crops and being easily reached by a low-volume spray. Another good example is afforded by the larvae of the pine sawfly, *Neodiprion sertifer* (Geoffr.), though in cases where the trees are above a certain height it may be necessary to spray from the air.

Perhaps the most difficult pests to control by means of viruses would be the soil-living insects. For example, there are two viruses which could be used against the leatherjacket, the larvae of *Tipula* spp., but the difficulties in applying the virus under these conditions are very great. On the other hand the soil seems to be a good medium for the application of the bacterium, *Bacillus popilliae*, which has been used with success against the larvae of the Japanese beetle.

Time of Application of Pathogen and Age of Insect

So far as the viruses are concerned the time of application and the age of the insect are important and intimately connected. It has to be remembered that unlike the effect of an insecticide there is a time lag, or incubation period of the disease, between the application of the virus and cessation of feeding. Timing in the application is therefore critical and the optimum time would be just before the hatching of the eggs. Bird (1953) considers that to prevent serious defoliation by the pine sawfly the virus should be applied before the larvae have developed to the fourth instar.

The age of the insect at the time of application of the pathogen has a further significance because there is now a good deal of evidence that larvae in their later instars are more resistant to infection with viruses than are the young larvae, and a larger dose would therefore be required.

Optimum Concentration of Pathogen

Field tests conducted at Geneva, New York, using commercially produced spores of *B. thuringiensis* against two cabbage insects gave good control of *Pieris rapae* when used at a dosage of 0·3 lb. per acre of a spore preparation containing 100 billion spores per gram. Against the cabbage looper, *Trichoplusia ni* (Hb.), however, this dosage was ineffective. Data obtained show that while good control of *P. brassicae* can be achieved with a relatively low dosage of *B. thuringiensis* spores, control of the cabbage looper requires a much higher rate of application. Larvae of these two species killed by ingestion of the spores of *B. thuringiensis* seldom showed any sign of bacterial infection but were apparently poisoned by the crystal present in the sporangium (McEwen and Hervey, 1959).

Another experiment using commercially produced *B. thuringiensis* spores against the alfalfa or lucerne caterpillar, *Colias philodice eurytheme* Boisd., has been carried out (Stern, Hall and Peterson, 1959). Both ground and air equipment was used for spraying, and in the case of ground equipment the spore material was applied over a range of 1·8 to 18·0 oz. per acre (each gram of spore material contained approximately 40 billion viable spores). Two days after application, control was satisfactory where 7·8 and 18·0 oz. of spore material was applied per acre, and excellent control was obtained with all bacillus treatments at the end of four days at dosages as low as 1·8 oz. per acre. The large larvae which are the most damaging were affected sooner than the smaller larvae.

The results suggest that 3 to 4 oz. of spore material per acre applied by ground equipment, and 4 to 5 oz. per acre applied by aeroplane give a control as satisfactory as can be expected with a chemical insecticide. As, however, the caterpillars apparently all died from poisoning and not from the bacterial disease the advantages over an ordinary insecticide are not obvious.

According to Beard (1944) experimenting with *Bacillus popilliae* Dutky against the Japanese beetle, the LD.50 is about two million spores per gram of soil.

As regards the concentrations of virus used, these vary somewhat according to the virus and the insect against which it is directed. In the case of the polyhedroses, Bird (1953) considered that mortality of the pine sawfly depends on the amount and concentration of virus used. Ossowski (1957) used an aqueous suspension of 10,000 polyhedra per/cu. mm. against the wattle bagworm, *Kotochalia junodi* (Heyl.), and found that there was no increased mortality when higher concentrations were used. Coaker (1958) found concentrations of 50–100,000 polyhedra cu. mm. effective against the cotton bollworm, *Heliothis armigera* (Hb.).

Thompson and Steinhaus (1950) observed that above a certain minimum concentration of polyhedra there is not a great deal of difference in the control effectiveness with varying concentration of the virus. In cold weather larvae of the alfalfa caterpillar came down with the disease about one day earlier than did those treated with lower concentrations.

That these insect viruses are highly infectious is shown by the fact that an oral dose of 0·001 ml. of an inoculum prepared by triturating the body contents of one virus-killed fifth instar cabbage looper in 16 litres of water killed all the larvae treated (McEwen and Hervey, 1958). We have found that five mature larvae of *Pieris brassicae* killed by a granulosis would make one gallon of highly infectious spray.

Ease of Production and Storage Capacity of Pathogen

The ease with which the pathogen can be produced, and the length of time it can be stored in a viable condition are important from the commercial viewpoint. The problem seems to have been solved so far as the spores of *B. thuringiensis* are concerned. These are now available commercially in the U.S.A., under the name of Thuricide from the Stauffer Chemical Co., and as Agritrol from Merck & Co.; this last is a wettable powder with seventy billion viable spores per gram.

As for the viruses, ease of production and viability in storage depend a good deal on the virus and insect host concerned. The viruses causing the nuclear polyhedroses are probably the most resistant to ageing since they remain viable for long periods even years so long as they are occluded in their polyhedral crystals. As to production in large quantities, since no virus will grow in a cell-free medium, those caterpillars which are easy to infect and can be grown all through the year will be the most productive. Comparatively large quantities of polyhedra can be obtained from the alfalfa caterpillar in California; the technique employed by Thompson and Steinhaus (1950) was to build up an initial supply by infecting caterpillars in the laboratory. This was then sprayed onto a natural population of caterpillars in the field, and after a period the diseased caterpillars were collected. By this means seven gallons of virus material were recovered in four hours time on the sixth and seventh days after application.

The granulosis viruses are less easy to store for any considerable length of time, but large supplies of virus can be built up. At the Virus Research Unit in Cambridge caterpillars of *Pieris brassicae* can be reared all the year round, and it is fairly easy to rear and infect some 20,000 larvae during the winter. From these about twelve gallons of virus material were prepared.

If the insect host is very small then the difficulty arises of obtaining sufficient virus for use in control. The larva of the clothes moth, *Tineola bisselliella* (Humm.) is a case in point; there is a virus causing a nuclear polyhedrosis which, on a small scale, appears to exercise considerable control. The main difficulty is to produce sufficient virus, and so far all attempts to propagate the virus in a larger insect have proved unsuccessful.

Method of Application

As a general rule the pathogens can be suspended in water and applied with a low-volume sprayer. Potts (1946) points out that fine atomisation is necessary to obtain adequate distribution with low gallonage, but the droplets must be large enough to deposit on foliage and insects. The optimum droplet size for ground application apparently should be twenty to eighty microns in diameter.

A fair application of virus against cabbage caterpillars would be about thirty gallons to the acre with a low-volume sprayer. Bird (1953) used a mist blower against the pine sawfly (*N. sertifer*) and found that the amounts of virus deposited varied with the distance from the spray source, the earliest mortality occurring near the spray source. When aircraft were used for spraying, it was observed that larvae died more rapidly at the top of the trees than did those feeding on foliage on the lower branches.

Field tests against *P. brassicae* on cabbage showed that the effectiveness of *B. thuringiensis* spores was enhanced by the addition of skim milk powder and vinyl latex as stickers (Jacques and Fox, 1960). Bird (1953) also found that skim milk powder added to his virus suspension caused an earlier mortality in the pine sawfly. We have also used a non-germicidal commercial brand of wetting agent with success in our virus suspensions. These are especially useful in helping the polyhedra or granules to adhere to plants like cabbages which have leaves with a waxy surface and are normally difficult to wet.

Persistence of Pathogens

One of the advantages of the use of pathogens, and especially the polyhedra, over the use of insecticides is their superior persistence. Fungi and bacteria apparently persist in the soil from one year to the next, and a more or less permanent infection can sometimes be set up. A case in point is the " milky disease " of the larvae of the Japanese beetle; once the turf or soil is impregnated with the spores of the bacillus it remains infectious for long periods of time and the supply of spores is continually increased by the breakdown of infected larvae.

The viruses contained in their polyhedral crystals are extremely resistant and once they are introduced into a susceptible insect population, they may spread and persist for many years. According to Bird the polyhedra of the spruce and pine sawflies are unable to persist over winter, but he was referring to Canadian conditions and there is little doubt that most kinds of polyhedra will withstand the ordinary winters of the British Isles.

Weather conditions affect the persistence of disease organisms more than they do the persistence of polyhedra. Fungi normally require moist conditions for the production and germination of their spores and many bacteria are susceptible to desiccation. On the other hand the polyhedra are relatively unaffected by weather conditions, and it is probably only prolonged exposure to very low temperatures which might inactivate the virus within the crystal.

Another and important aspect of polyhedral persistence is the transmission, at all events in some cases, from parent to offspring. This is dealt with in a later paragraph.

Population Density

As a general rule it may be said that disease is a density-dependent factor of mortality, *i.e.*, it affects a greater proportion of the population as the density of the population increases. Thus insects that live in aggregations or that form large populations are more susceptible to epizootics than are those at low population densities (Bucher, 1958). However, a pathogen like *B. thuringiensis*, where the spores are toxic, acts more like a chemical insecticide which is density independent with its effect unrelated to population density.

In experiments in Canada on the control of the spruce sawfly, *Diprion hercyniae* (Htg.) with a polyhedral disease, the efficiency of the polyhedrosis appeared at first to be density-dependent, being effective at high and ineffective at low densities. However exceptions to this were observed during years following a severe virus epizootic when the disease was effective also at very low host densities. The reason for this appears to be that during a severe virus attack many insects become infected late in larval development, survive and pass the disease on to their offspring (Bird and Elgee, 1957). We have observed this phenomenon in a small-scale experiment near Thetford in Norfolk; we were using a polyhedral disease against *Neodiprion sertifer* on Scotch pine and in the first year of application the mortality rate was very high. On visiting the area the following year we found that there were very few larvae, and those were mostly already infected with the polyhedrosis without any further application. The virus had undoubtedly been passed transovarially from the insects infected late in the previous season.

It can be assumed therefore that density-dependent and density-independent factors are both involved in epizootic dynamics, but Steinhaus (1954) is of the opinion, that speaking generally, disease is essentially a density-dependent mortality factor.

Genetic and Secondary Means of Spread

So far as the viruses causing the polyhedroses and granuloses are concerned there is no doubt that these viruses are passed from parent to offspring. This is, of course, important in biological control because it is thus possible to affect unborn populations of insects in a way no chemical insecticide can do. Inheritance of virus is also instrumental in spreading viruses over a distance since the winged adult is capable of flying to new districts.

We have fairly unequivocal evidence that the granulosis viruses are transmitted to the progeny of the white butterflies, and, apart from the circumstantial evidence of field trials, C. F. Rivers has proved the transmission from parent to offspring of the polyhedral virus infecting *Neodiprion sertifer*, the pine sawfly.

As regards secondary methods of spread of viruses, both the wind and the rain are likely to disperse the polyhedra over neighbouring plants or even further afield. There is also the possibility of spread by predacious insects and by parasites. It is a moot point whether parasitic insects are able to pick up and transmit insect viruses on the point of the ovipositor.

As a matter of interest in this context it may be worth mentioning that the semi-liquid cadavers of *P. brassicae* larvae which have died of granulosis seem to have an attraction for the healthy larvae which feed upon them with disastrous results.

Latent Virus Infections

One of the interesting characteristics of insect viruses is the widespread occurrence of latent infections. This is particularly true of certain insect populations, such as the spruce budworm; in Canada according to Bergold it is difficult to find any insects of this species which are virus-free. Latent infections are also common in the silkworm, *Bombyx mori* (L.), the tiger moth larvae and many other species. Anyone who has tried to rear large quantities of caterpillars in captivity will be aware of the rapidity with which a virus disease appears and spreads through the insect colonies.

It is possible to " trigger-off " these latent infections in a variety of ways; these are called " stressors " by Steinhaus (1958) who has made a preliminary study of stress as a factor in insect disease. Of natural stressors, crowding and temperature conditions are the commonest; the greater the number of insects confined in a given space the greater the incidence of disease among them. Heat may possibly have some effect on bacterial infections but at present there is no evidence that high temperatures induce the appearance of virus diseases. I have found that low temperatures and high humidity appear to stimulate into virulence a polyhedrosis in larvae of *Cerura vinula* (L.), the puss moth. Steinhaus found no evidence to support Yamafugi's claim that a polyhedral disease could be induced *de novo* in silkworms by means of chemical feeding. He had negative results also with triturated glass, alteration of nutrition by the substitution of abnormal food materials and ultra-violet light. Steinhaus does not mention, however, the use of a foreign virus to stimulate latent infections into activity, and this we shall discuss later.

Acquired Resistance

Our knowledge on the possible development of resistance to pathogens on the part of insects is very slight, although it seems generally accepted that they do not develop antibodies. The only case of apparent acquired resistance to virus infection of which I am aware concerns the larvae of *Pieris brassicae* and the granulosis. Rivers (1958) studied the outbreak of granulosis in a laboratory culture in order to observe the way in which a colony could recover from an epizootic. At the height of the disease only about 1 per cent. of the larvae survived but with these few it was possible to build the culture up to full strength again. Experiments with these laboratory stock larvae showed that their resistance to infection with granulosis virus was significantly greater than that shown by *P. brassicae* larvae from other sources. This resistance can be overcome, especially during the first and second instars, by using very large doses of virus. There is little information on the mechanism of this resistance.

In some separate experiments we obtained evidence that passage of the granulosis virus through another species of *Pieris*, *P. napi* (L.), enabled the virus to overcome the resistance shown by the *P. brassicae* larvae.

Combined Use of Pathogens

Occasionally a combination of virus and bacterium or a combination of two viruses have a synergistic effect and are more efficacious than either pathogen acting alone. For the control of the alfalfa caterpillar a mixture of polyhedra and bacillus spores can cause a faster reduction in population than the virus alone, but the control obtained appears to be less complete or long lasting than that from the virus alone. It has been suggested that a combination of *B. thuringiensis* and polyhedrosis virus might be more efficacious against the cabbage looper than either pathogen acting alone (McEwen and Hervey, 1959).

Production of New Virus Diseases

The production of new virus diseases in insects is not only of great scientific interest but has also a practical significance. There are two methods of bringing about the phenomenon of an apparently new virus infection of an insect. Firstly, a latent virus infection can be "triggered off," or stimulated into action, in an insect species in which no natural virus disease has ever been recorded. Secondly, it is possible in some cases to produce a virus disease by cross-inoculation of a foreign virus into an insect pest of which no virus is known.

We can give two cases of artificial stimulation of a latent virus infection; we have seen earlier the use of stressors to stimulate latency, but these experiments did not employ another virus to this end.

We have long looked, without success, for a virus disease of the winter moth larvae, *Operophtera brumata* (L.); so the following experiment was carried out to try to stimulate a latent virus infection. Two batches of winter moth larvae in a middle instar were used, and half were fed on leaves coated with polyhedra from a nuclear disease of *Vanessa cardui* (L.), the painted lady butterfly; the other half were kept for a control. In about ten days the inoculated larvae commenced to die of a virus disease, the final mortality being about 90 per cent. Examination revealed that the virus disease from which the winter moth died was a cytoplasmic polyhedrosis whereas the virus with which they had been inoculated was one causing a nuclear polyhedrosis. The virus thus obtained was then infective for other winter moth larvae (Smith and Rivers, 1956).

This technique has also been used to evoke a polyhedral virus disease in Neuropterous insects, an order from which no virus had previously been described. When larvae of *Chrysopa* spp. and *Hemerobius* spp. are fed upon pieces of *Lymantria dispar* larvae which had died of a polyhedral disease, a proportion of the Chrysopids and Hemerobiids died of a very similar polyhedral disease. Although the two diseases are somewhat similar in appearance, it seems more likely that the causative viruses are distinct (Sidor, 1960; Smith *et al.*, 1959).

The second method of producing a new virus disease is by genuine infection with a foreign virus.

For many years it had been accepted that insect viruses were more or less species-specific and that cross-transmission was a rare occurrence. However, a paper by Smith and Xeros (1953) had already thrown doubt on this axiom but the criticism had been made that it was difficult to differentiate between a genuine cross-transmission and the stimulation of a latent virus infection. The discovery of a new virus in the larvae of *Tipula paludosa* Mg. has enabled the cross-transmission work to be repeated without the complication of latency being involved. This virus, known as the *Tipula* iridescent virus, has remarkable properties which differentiate it immediately from all other known insect viruses, so that it can be used as a marker. The chief characteristic is the production of a blue or violet iridescence in the infected larva; this is due to the micro-crystals of virus which form within the living insect and have this peculiar optical effect. We have been able to transmit this virus not only to many different species in the Diptera, but also to many species in the Lepidoptera and Coleoptera (Smith and Rivers, 1959). Among insects of economic importance in which we have induced a virus infection may be mentioned *Calliphora vomitoria* (L.), the blowfly; *Lymantria dispar*; *Pieris brassicae*, *Tenebrio molitor*, the mealworm, possibly the wireworm and a species of Melolonthid larva. We have now perfected a method of large-scale production of the *Tipula* iridescent virus by using caterpillars of *Pieris brassicae*, the same technique as that used for the mass-production of the granulosis virus. This latter method for inducing new virus diseases in insects is admittedly mainly of scientific interest at the moment but it does suggest possibilities for future developments in biological control.

Some Examples of Biological Control with Viruses

We have mentioned the work of Steinhaus and his co-workers (Thompson and Steinhaus, 1950) on the control of the alfalfa caterpillar with a polyhedral disease, of Bird and his colleagues (1953) against *Neodiprion sertifer*, the pine sawfly, with a similar type of virus, and of Ossowski against the wattle bagworm (1957).

In this country so far our efforts have been confined to small-scale tests of viruses against the larvae of *Pieris brassicae*, *Tineola bisselliella*, the clothes moth, and on a larger scale against *N. sertifer*, the pine sawfly. My colleague, C. F. Rivers, has been responsible for most of the work on *N. sertifer* and there were two separate trials. The first small field trial was carried out in 1957 on a heavy infestation near Thetford, Norfolk. Forty-one litres of virus suspension were used to spray about 180 trees at the south end of the plot. The suspension contained 200,000 polyhedra per ml., and a knapsack sprayer with a T boom with two outlets and ceramic nozzles size 000 at 40 lb. per sq. in. was used to disseminate the virus.

An assessment was made three weeks after spraying; only four larvae per tree were recovered on average from 26 trees selected at random in the sprayed area. In the control section no virus-diseased larvae were found and one in six of the trees were totally defoliated. On a visit to the plot the following year we found that the virus had affected all the sawfly larvae on the plantation in both the sprayed and the control areas; all the larvae had died before any appreciable damage was done.

In May 1959 the work was repeated on a larger scale at Ballachulish in Scotland. A Kiekens 75W powered mist-blower giving a very small droplet size was used and the virus was applied at the rate of one-and-a-half gallons per acre. After a fortnight the forester collected at random twelve colonies of larvae; eight colonies contained many infected larvae and the other colonies became ill after a few days. Two weeks later the forester reported that the virus had produced drastic results and it was difficult to find any larvae at all. Rivers visited the site in mid-June and was able to confirm that the control had been most effective. A report from the forester dated 17/5/1960 states that a survey carried out on the same date as that of the outbreak the previous year showed no sign of larvae.

Some Insect Pests for which Viruses have been found.

LEPIDOPTERA

Phlogophora meticulosa (L.), angleshades moth.
Euplexia lucipara (L.), small angleshades moth.
Agrotis segetum (Schiff.), turnip moth or cutworm.
Triphaena pronuba (L.), yellow underwing.
Diataraxia oleracea (L.), tomato moth.
Melanchra persicariae (L.), dot moth.
Euproctis chrysorrhea (L.), brown tail moth.
Biston betularia (L.), pepper and salt moth.
Abraxas grossulariata (L.), currant moth.
Bupalus piniarius (L.), pine looper.
Operophtera brumata (L.), winter moth.
Aporia crataegi (L.), black-veined white butterfly.
Pieris brassicae (L.), large white butterfly.
P. rapae (L.), small white butterfly.
Natada nararia (Moore), " nettle-grub " of tea (Ceylon).
Tineola bisselliella (Hummel), clothes moth.
Tinaea pellionella (L.), case-bearing clothes moth.

HYMENOPTERA

Neodiprion sertifer (Geoff.), pine sawfly.
Nematus olfaciens Benson, black-currant sawfly.

DIPTERA

Tipula paludosa, leatherjacket.

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A Virus Disease in the Biological Control of the Wattle Bagworm

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The estimated total area of forest in the Union of South Africa is nearly 9,000,000 acres, of which approximately 2,500,000 acres are exploitable. These consist of some 500,000 acres of indigenous trees and 2,000,000 acres of exotic species, mainly wattles, pines, eucalyptus, and poplars (Anon. 1957). Black wattle, *Acacia mollissima* Willd., introduced from Australia nearly 100 years ago, today covers about 800,000 acres, earning the country approximately £6,000,000 annually for dry bark and bark extract, but not including timber. For the latter commodity, no reliable figures are at present available, but it is estimated that the total production exceeds 2 million tons per annum. The rotation of the crop is about ten years and the average bark yield approximately six tons of green bark or about three-and-a-half tons of dry bark per acre.

With the introduction of black wattle and the establishing of large, compact, plantations, conditions favourable to the development of endemic insect pests were created. The indigenous wattle bagworm, *Kotochalia junodi* (Heyl.)—belonging to the *Psychidae*, whose natural host plants are the thorn trees belonging to the various species of *Acacia*—began to invade cultivated wattle some ten years after the introduction of this tree into South Africa, and by the end of the 19th century was regarded as a potential wattle pest. Since then, it has increased rapidly in these plantations, and is now an integral part of their insect life and the commonest and most destructive of all wattle insect pests.

The building up of an infestation, which requires some five to seven years to reach its peak, after which it returns to its latent stage, depends mainly on climatic conditions and nutritional, plant physiological, and other environmental factors. Hymenopterous and dipterous parasites are fairly prevalent on bagworms, some Coleoptera, Hemiptera and Araneae prey on them, and pathogenic micro-organisms are responsible for natural mortality.

Complete defoliation of trees usually occurs twice during the eruptive stage of an infestation and as a result, plantations lose increment of approximately 0·75 ton of green bark per acre in each year of defoliation. If defoliation takes place in the year of, or one year prior to, felling, the stripping of some trees becomes difficult or even impossible.

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* It is greatly regretted that Dr. Ossowski was taken ill whilst on his way to attend the XIth International Congress of Entomology at Vienna and died in London on 21st August, 1960.

In the past ten years, over 100,000 acres were infested annually, with 10,000–12,000 acres completely and over 20,000 acres partially defoliated.

To combat this pest, natural cryolite was introduced about 1930 and used for some years, being applied first from the ground and later from the air. It gave promising results, but only when weather conditions were favourable, *i.e.*, when for some six days after application there was no strong wind or rain to blow away or wash off part of the deposit. Since, however, plantations must be treated between October and December, which is in the rainy season, such conditions could not be relied upon, and commercial application of cryolite was discontinued because of the uncertain results. At present, toxaphene in light diesel oil is the insecticide mainly used. BHC and endrin have also been tried, but there was no significant difference in efficacy between the three insecticides when larvae were in their early instars; endrin, however, was more effective against older larvae. During the past eight years, approximately 82,000 acres have been sprayed from the air with insecticides. These campaigns, supplemented by two large-scale aerial spraying experiments, have shown that, if treatment is organised properly and carried out efficiently under favourable weather conditions, satisfactory results can be obtained in some categories of plantations, but only in terms of a single season. Today, the only areas recommended for spraying are mature or nearly mature plantations, where treatment is necessary to facilitate stripping of bark, and some young plantations, especially those growing on marginal areas.

It has long been known that a polyhedral wilt disease, first mentioned some forty years ago, is one of the biological control factors involved in maintaining the natural balance of bagworm populations. Results of two cage experiments (Skaife, 1920) showed that larvae fed on foliage sprinkled with an aqueous suspension obtained from infected bagworms died within three weeks, while in control cages the number of larvae which succumbed to this disease was negligible. These experiments, though in no way conclusive, indicated that the disease was contracted through ingestion of contaminated food and suggested the possibility of using the virus as a biological control measure.

The causal agent of the polyhedral wilt was first isolated and described in 1955, when the disease was re-investigated (Ossowski, 1957, 1958). When smears from the body contents of affected larvae were stained with Giemsa solution and examined under an oil-immersion lens, polyhedral bodies were seen unstained against a stained background, and were thus identified as belonging to the nuclear type in contrast to the cytoplasmic one, which readily takes up the stain. These bagworm polyhedra are highly refractive bodies varying greatly in size, which may range from $0 \cdot 25\mu$ to 3μ. Their shape is mainly many-sided, but tetra- and rhombohedral forms may also be found. When the polyhedral crystals are treated with weak sodium carbonate, they dissolve, leaving behind a thin membrane containing rod-shaped particles about $250 \text{ m}\mu \times 25 \text{ m}\mu$. The number within one membrane varies with the size of the particle and that of the polyhedron, but up to eighty have been found.

In the wattle bagworm, the polyhedra occur mainly inside the nuclei of the fatbodies, epidermis, tracheae, and blood cells of the larvae and, less frequently, of the prepupae and pupae. In larger larvae, they are sometimes found also in the nuclei of cells of the perineurium and the neurons of the abdominal ganglia.

From 1955 onwards, experiments have been in progress to determine whether the wattle bagworm could be controlled by artificially increasing the concentration of virus and whether epizootics could be initiated.

In the first pilot experiment, when aqueous suspensions containing from 10,000 to 250,000 polyhedra/cu.mm. were applied, newly hatched larvae became moribund after three to four days feeding on virus-contaminated foliage and died two days later. Older larvae died more slowly. As it was found that the concentrations applied were unnecessarily high, the maximum effectiveness being reached at the lowest density, *viz.*, 10,000 polyhedra/cu. mm., a further series of experiments was conducted in the following year on a somewhat larger scale, using lower concentrations of virus, *viz.* 1,000 to 10,000 polyhedra/cu. mm. Again there was no difference in the total kill whether higher or lower concentrations were used, but another highly significant fact emerged, namely that mortality was higher in plantations sprayed with virus introduced from a distant source than in those in which suspensions prepared from local material were applied. This suggested that there might be different strains within the nuclear type of virus found in the bagworm.

In order to obtain further evidence on this possibility, as well as on the effect of virus on bagworms and on the course of an infestation cycle, some 500 acres of plantations in different parts of the wattle-growing area were sprayed from the air in 1957. Suspensions of still lower concentrations and of different origins were tried against newly-hatched and older larvae at various stages of the infestation cycle. When infestation was in the prodromal stage and the larvae in their first instar at the time of spraying, there was no marked difference in mortality whether suspensions containing 1,000 or 500 polyhedra/cu. mm. were applied. Suspensions of 250 polyhedra/cu. mm. gave a lower kill, but mortality was still high enough to keep the crowns green. With the higher concentrations, the course of the cycle was accelerated and the eruptive stage and the crisis occurred later in the season, whereas with the lowest concentration, the infestation decreased gradually after spraying. In unsprayed plantations, the infestation became more severe as the season progressed, and reached the first year of the eruptive stage the following year.

Against older larvae, the initial kill was too low to prevent defoliation, but nine months after spraying, mortality had increased sufficiently to reduce the population to its basic level. Where virus was applied during the eruptive stage, there was a very high initial kill, but nine months after spraying, mortality was equally high in treated and control plots.

Up to six months after spraying, the kill was always higher where virus of introduced stock was applied than with suspensions containing local material, but nine months after application, there was no difference between introduced and local virus.

As the last experiment was a large field trial, primarily designed to investigate control measures, a more critical and accurately controlled experiment was laid out in 1958 specifically to investigate suspected strains. Plantations of young trees were selected for uniformity of crowns and bagworm population, and randomised, replicated single tree plots laid out in them were sprayed at various stages of development of larvae and the infestation cycle, with virus suspensions from different sources. With a light infestation in the first year of the prodromal stage and the larvae newly-hatched or in the second or third instar (virus concentrations were doubled in this latter case), viruses from a plantation distant from the experimental areas caused a significantly higher mortality throughout than when local material was used. With a heavy infestation in the second year of the prodromal stage and the larvae at the time of spraying in the first instar, mortality was significantly higher only initially with virus from the greatest distance. These results confirm that different strains of the bagworm virus exist and that a given population of bagworms is more susceptible to some strains than to others.

In 1959, a more detailed extension of the last-mentioned experiment was carried out, in which viruses from two sources only, applied at various stages of the development of the larvae, were compared over a range of concentrations. An interim assessment of the results confirms the outcome of the earlier experiment with regard to variation in virulence of the bagworm virus.

Stickers in the form of methylcellulose and skim milk powder were added in some experiments. The former did not increase mortality, and where milk powder was used, the kill was always lower due to intermittent clogging of the nozzles with subsequent uneven distribution of the suspension through the crowns. In some experiments, over 1,000 mm. of rain fell between the time of spraying and the last sampling, without apparently impairing the distribution and efficacy of the polyhedra. This suggests that there is little danger that the polyhedral bodies will be washed off the trees by rain, probably due to the pubescence of black wattle leaves.

A gradual spread of the effect of virus was evident in plantations kept under observation. Plots sprayed in 1955 and 1956 and examined in the following three or two years respectively were practically free of bagworms. Infestation was negligible in plantations bordering directly on those sprayed, but its severity was greater in blocks further away. In 1959, the bagworm population started to increase again in the treated plots, but was still at a low level, while in neighbouring, unsprayed plantations infestation was severe. On a 900 acre wattle farm surrounded by a further 10,000 acres of wattle plantations, 135 acres were sprayed in 1957 with virus suspensions. In the sprayed plantations, as well as in some fifty acres directly bordering on them, the bagworm population remained at a low level, the crowns were green in the year of treatment and in the two following years, and the trees could be stripped, while plantations in nearly the whole district were partially or completely defoliated. This seems to indicate that virus can promote epizootics and also influence to some extent the population dynamics of bagworms, but further experiments over a larger area are necessary to obtain more evidence on the latter issue. It may be asked why polyhedral wilt occurring naturally in bagworms does not normally become epizootic. The explanation lies in the uneven distribution and low density of natural virus, coupled with the almost static behaviour of the larvae. Once settled on the fodder tree, larvae do not move far and may not come in contact with food sufficiently contaminated with virus to cause death. Larvae leave a tree in search of food only if it becomes completely defoliated.

Viruses are dispersed in plantations by insect parasites through mechanical transmission of the virus, on the ovipositor (Thompson and Steinhaus, 1950). Bugs, birds and mammals, feeding on virus-infected bagworms, may transmit and spread virus particles through their droppings, since the virus remains effective after passing through the alimentary system of these animals (Bird, 1955, Franz, Krieg and Langenbuch, 1955). In bagworm populations, an additional factor favourably influences the retention and distribution of virus particles in plantations through several years. Dead larvae, pupae, and adult females remain in bags on the trees for three or even more years, disintegrating slowly, and if the insects were killed by virus disease, virus particles are consequently released and dispersed through plantations during several years. In the case of the bagworm where virus density has been artificially increased, it would appear that this fact explains the carry over of an infection through several years and the retention of the bagworm population at a low level.

The virus does not affect hymenopterous and dipterous parasites, since healthy pupae and larvae of *Charitopimpla sericata* (Krchb.)—*Ichneumonidae* and *Carcelia evolans* (Wied.)—*Diptera*—or *exuviae* and empty cocoons of these very important parasites of *K. junodi* were plentiful in bags with bagworms which had died of polyhedrosis.

These experimental results suggest that if virus is to be used in older plantations to keep the crowns green to prevent loss of increment and to facilitate stripping, suspensions, preferably of introduced origin, should be applied during hatching of the larvae, thus ensuring a high kill. Where, however, young plantations are to be kept free of bagworms or at a low level of infestation through as many seasons as possible in the ten-year rotation, it may be advisable, even at the risk of losing some increment during the first year of application, to postpone spraying till the bagworms have reached the third or fourth instar. Infected late in life, some may survive and transmit the virus through the eggs to the next generation (Bird, 1954). Those which succumb to the disease will be larger, producing a greater quantity of virus to be dispersed over the plantation than do the very small first-instar larvae. A combination of spraying of some plantations at the time of hatching and some later in the season may, in appropriate cases, be advisable and prove advantageous.

The preparation of bagworm-virus suspensions for large field trials is not very difficult. The larvae feed and nearly always pupate on the same tree on which they have settled shortly after hatching, and can thus easily be collected. The yield of polyhedral crystals varies and depends on the severity of the infestation and the size of the moribund or dead insects. Experience has shown that usually ten fourth-instar larvae, killed by the virus disease, produce enough polyhedra to prepare suspensions to treat one acre of a three-year-old plantation. In spite of this, however, it is important, as it is in all such cases, to develop methods of mass-producing the virus in tissue cultures. Little progress has so far been made anywhere towards a satisfactory solution, but recent developments in this direction are to be discussed in the Section on Insect Virus Research at the forthcoming International Congress of Entomology in Vienna.

It would thus appear that the use of this virus in combating the wattle bagworm has distinct possibilities. Some problems have been solved, but others have arisen in their train, and though results obtained so far are very promising, much additional testing under a wide range of conditions in the field will be necessary before definite and sound conclusions can be reached and application safely recommended as a routine control measure.

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Discussion

The Chairman thanked the speakers, and then opened the discussion by asking Dr. Smith to what extent it was possible to infect an insect with a single virus particle. Dr. Smith replied that the assay methods so far developed were not sufficiently sensitive to detect infection at that level, but he could say that infection was possible with a single crystal of a polyhedral virus although incubation then took longer than normal.

Mr. D. J. Colwill asked whether there were any dangers to the operator in the use of insect viruses, especially in long-term insect control, and he also wondered whether insects developed resistance or immunity to the viruses, and whether the mutants known to occur when foreign viruses were passed through insects could be pathogenic to other groups of organisms including man. Dr. Smith first of all rejected the idea of insect immunity, as no antibodies had yet been demonstrated in insects. There was a single case of *Pieris brassicae* (L.) having been resistant to a virus: during an epidemic of granulosis, 1 per cent. of the larvae survived, and when bred showed definite resistance although virus from those specimens were still pathogenic. No mutations harmful to man had been encountered, and the speaker was still alive after a working life devoted to the study of insect pathogens; the physiological differences between insects and man were so wide that a virus would need great modification to bridge the gap.

Mr. M. E. Solomon asked what Dr. Smith thought of the possibility of a virus applied to kill a pest acting also against beneficial insects, or even spreading over wide areas and upsetting natural relationships in undesirable ways. Dr. Smith said that viruses were remarkably host specific, with the exception of the Universal Virus. A virus acting against *P. brassicae* would kill only other Pierids, and although some five years ago collectors in Britain had been alarmed at the possible effects of the use of viruses on the Lepidopterous fauna, their fears were as yet unrealised.

Dr. F. J. Simmonds, remarking that stress had been placed on the use of viruses by spraying them on infested crops, asked Dr. Smith if he would enlarge on the possibilities of using viruses [especially those induced in unnatural hosts] as biological agents to be introduced into new areas. Dr. Smith replied that his work had not reached that far. The *Tipula* Iridescent Virus [TIV] would attack nothing but *Tipula*, although they hoped at Cambridge to alter it in the course of time. Dr. Ossowski said that the virus of wattle bagworm would attack some other pests of wattle, but other viruses, such as the nuclear polyhedral virus from cotton bollworm, were not effective against the wattle bagworm, and beneficial insects had not yet been killed.

Mr. P. T. Walker asked whether virus infections caused any macroscopic symptoms to appear in the pupae, such as would be associated with the action of the moulting hormone, to which Dr. Smith replied that no early signs were visible with granulosis, but TIV attacked the wing-buds. Differences between insects sometimes occurred; thus pupae of *P. brassicae* showed no abnormalities when infected, whereas those of *Lymantria dispar* (L.) did.

Mr. F. Wilson pointed out that the majority of virus diseases had been recorded from the Lepidoptera, and he asked whether that was an indication that the Lepidoptera were particularly susceptible to viruses or that more attention had been paid to them, to which Dr. Smith replied that the apparent supremacy of Lepidoptera was due simply to the maldistribution of research in the past. At first, all the viruses isolated had been from Lepidoptera and Hymenoptera, but they had now been obtained from the citrus red mite and Tetranychids, and even from nematodes [which posed considerable extraction problems]. About the only organism not yet found to be attacked by a virus was another virus.

Dr. P. Faulkner asked, in relation to the simulation of a latent virus by a second virus, whether the latter was usually from a closely related species of insect and whether the induced condition was more likely to be nuclear or cytoplasmic. Dr. Smith said that in the work at Cambridge a nuclear virus had been used from a butterfly on a moth and that it nearly always triggered off a cytoplasmic virus, but an exception had recently been noticed in which the nuclear virus triggered off another nuclear form.

The Chairman suggested that the initiating virus had to be given as an unusually heavy dose, and Dr. Smith agreed with that. He explained, in answer to a question by Dr. F. Raw, that it was the latent virus that subsequently killed other insects.

Dr. I. Thomas asked whether, when a virus was transmitted via the egg, it sometimes remained latent in the following generation, and at what stage it re-appeared. Dr. Smith replied that it could remain quiescent for five or six generations, only to re-appear when some condition such as overcrowding or some other aspect of stress started it off. The stage of the insect attacked was invariably larval, but at no particular instar.

Dr. W. H. Hodson asked Dr. Smith to what stage he had progressed in ascertaining the viability of viruses in the absence of the host under natural conditions, to which Dr. Smith responded that it depended on the virus. There was a considerable literature on the subject; nuclear polyhedra of the silkworm could persist for fifteen years but were inactivated by freezing, and granulosis viruses often overwintered with a loss of about 50 per cent. Free viruses in general had a short life.

Dr. K. Mellanby suggested that there could well be a correlation between the action of viruses and the presence of the moulting hormone in insects, depending upon the stage at which the virus acted. Death from heat, for example, usually had its effect at a later moult than when the stress was applied. He then asked Dr. Smith [i] how often he had found that viruses from one insect would attack a second species, and [ii] whether the " billions " referred to in his paper were American or British. Dr. Smith said that the quantity was American *i.e.*, 1,000 million. With regard to the specificity of viruses, he said that with TIV it was the insects that it would not infect that were of more interest than those it would infect, but he referred to Dr. Rivers for further elucidation on that point. Dr. C. F. Rivers said that under natural conditions there was no cross-transmission of insect viruses, although it had been achieved by Smith and Xeros when large amounts of virus were used in the inoculum. New viruses were tested at the Virus Research Unit, Cambridge, against a wide range of insects, of which the most useful were some of the common Lepidoptera. He said that the granulosis virus of *Pieris brassicae* (L.) was effective against *P. napi* (L.) and *P. rapae* (L.), but harmless to larvae of Sphingidae, Saturniidae, Arctiidae and Selidosemidae, whereas the virus of *Bombyx mori* (L.) was transmissible to Sphingids. Most Lepidoptera had specific latent viruses. The value of this lack of cross-infection in the field had been shown when a virus of *Neodiprion sertifer* (Geoffr.) had been sprayed on pine trees and all the other insects present remained healthy. He was convinced that the use of viruses presented no danger to innocuous and beneficial insects when applied as a biological control agent.

Mr. F. Wilson pointed out that, although the use of a virus might harm no other insects directly, natural enemies of the pest against which the measure was applied would be deprived of their food. It had been found in Australia that the use of a virus against *P. rapae* had resulted in more than 95 per cent. mortality of larvae of *Apanteles glomeratus* (L.). The use of *Bacillus thuringiensis* against cabbage pests had been objected to in Australia because of its potential harmful effects on *Cactoblastis cactorum* (Berg.) on prickly pear, and he asked Dr. Smith whether that had been a valid and logical objection. Dr. Smith said that it was not likely to be a valid objection, but he would prefer entomological evidence on the subject. With regard to Mr. Wilson's first point, there was no getting away from the fact that, if you reduced the numbers of the host insect, the numbers of other insects were reduced proportionately.

Dr. W. A. L. David drew attention to Dr. Smith's remarks on the egg transmission of virus in the garden tiger moth [*Arctia caja* (L.)]. As, he said, the virus could remain latent and not re-appear as a disease until the operation of some stress factor induced an outbreak probably several generations later, he wondered whether the presence of virus had actually been demonstrated in eggs which then gave rise to healthy larvae, or whether its presence was presumed. He thought that, for reasons not understood, it might be possible for transmission to fail in certain generations. Dr. Smith replied that its presence was inferred because there was no infection. It was hopeless to determine virus in eggs unless it was present in exceptionally large quantities. The presence of virus in larvae could sometimes be demonstrated by trituration, but the examination of sections was not a worthwhile occupation.

Mr. D. W. Williams enquired whether the triggering-off of a latent virus infection by inoculation with another virus had been known to occur in nature, such as when a predacious insect fed on infected prey, to which Dr. Smith replied that there was only one case known, in which a Hemerobiid had fed on diseased *Lymantria dispar*.

DISCUSSION ON RECENT ADVANCES AND CURRENT TRENDS IN THE STUDY AND CONTROL OF TSETSE FLIES AND TRYPANOSOMIASIS

Chairman: Dr. T. A. M. Nash, *formerly Director, West African Institute for Trypanosomiasis Research*

The Chairman opened the meeting by expressing his delight and that of the gathering at the presence of Dr. S. A. Neave in the hall. Dr. Neave's interest, when at the Commonwealth Institute of Entomology, had been a factor in the changed status of entomology with regard to trypanosomiasis research. That change was indicated by the inclusion of the words " . . . and trypanosomiasis " in the title of the session.

Before the war, the general tendency had been for doctors to concern themselves with human sleeping sickness, occasionally aided by an entomologist, for veterinarians to concern themselves with animal trypanosomiasis, and for entomologists to concentrate on the ecology and control of tsetse flies. With the formation of the East and West African Research Institutes—E.A.T.R.O. and W.A.I.T.R.—doctors, entomologists, veterinarians, protozoologists, biochemists and zoologists had all been working together to their mutual advantage.

The research entomologist's horizon had been greatly extended by the much closer cooperation which now existed between the different professions, both in the research institutes and in certain technical departments. He might find himself trying to gauge the natural trypanosome challenge in a veterinary drug trial, or relating the incidence of sleeping sickness to the degree of man-fly contact, or evaluating the economic importance of different species of tsetse in accordance with their infection rates. His horizon had been extended to include epidemiology.

Thanks to Mr. B. Weitz, of the Lister Institute, who had perfected serological tests for the identification of the sources of tsetse blood-meals, a new bridge now linked the ecology of the tsetse with the epidemiology of trypanosomiasis. For each species of tsetse there had to be a linkage between the preferred host species, their suitability as trypanosome reservoirs, the degree of infection in the flies, and the incidence of trypanosomiasis found in man and his stock. Those links were now being examined.

At a time when rising labour costs were making the classical methods too expensive, said Dr. Nash, entomologists engaged in the control of riverine tsetse had revolutionised their methods by taking advantage of modern insecticides. Unfortunately, the use of insecticides for the control of woodland tsetse often presented greater difficulties.

Recent Advances in Tsetse and Trypanosomiasis Research and Reclamation

By Mr. J. Ford

Department of Tsetse and Trypanosomiasis Control and Reclamation, Southern Rhodesia

When, in 1954, the late Dr. Jackson addressed this Conference, he devoted most of his paper to methods of reclamation from tsetse-fly infestation. He gave a third of his time to research and did little more than mention the trypanosomes which the tsetse flies transmit. It is a measure of the great change that has taken place in the last ten years (for it had already begun in 1954) that I shall have little time to devote to tsetse fly reclamation but much to research and that most of the research I shall consider is concerned with *Glossina* in its role as a vector of trypanosomes.

What are the reasons for this change of emphasis? In part, of course, to the establishment of larger research institutes. But research into a problem is often conditioned by the techniques available for its solution in the field. It is often concerned less with inventing new methods than with understanding those in use and their more efficient application. One important innovation was foreseen by Dr. Jackson. Discussing insecticides he said " what we need is a really good residual effect on the perching places " of the tsetse. We now have one in dieldrin and no doubt Mr. Hocking will discuss its use; but the fact that it exists has greatly stimulated research on the resting sites of *Glossina*, or rather its behaviour when not attacking the observer. But undoubtedly the main cause of our re-assessment of the " tsetse problem " has been the discovery of drugs which have a relatively prolonged prophylactic effect in protecting cattle against trypanosome infections. The introduction of antrycide in particular, though other drugs are now in use as well, has completely revolutionised the practical problem presented by the tsetse fly. Ten years ago the " last fly " had to go before success could be claimed: in 1957 Kenya workers stated that " If land can be used without danger by people or cattle then ' reclamation ' has been achieved, whether tsetse flies remain or not " and today hundreds of thousands of African cattle are pastured where, ten years ago, this would have been impossible. To many field workers the problem today is, first to create the conditions under which drugs may be used economically. Whether or not it will be worth while to proceed with anti-tsetse measures to the point where the fly is eliminated, is a secondary consideration. A consequence of this is that research has very largely turned towards *Glossina* as a vector of trypanosomes and this, in turn, is eliminating the dichotomy which has hitherto existed between research directed towards solution of the veterinary problem and research on sleeping sickness: between East Africa, concerned largely with cattle and West Africa with human trypanosomiasis. In both we are now dealing with the tsetse fly as a vector of disease.

Six or seven years ago workers in both West and East Africa began to turn their attention to the whereabouts of *Glossina* when it was not attacking the observer. I am more familiar with the East African studies and may therefore be forgiven if I deal only with them. When planning this research I recall that we first thought of more difficult methods: we thought of marking tsetse flies with radioactive substances, releasing them and then tracking them down with a Geiger counter. Fortunately this was not practicable. Then we decided to mark flies with fluorescent paints and to search for them at night with an ultra violet light. This was a useful idea, but eventually we did the simple thing and went into the bush to look for them during the day. It may seem odd that we did not do this at once, but we were obsessed with the idea (which was why the early work on these lines, for example, by Moiser in West Africa in 1912 was never followed up) that if we did find any tsetse sitting on trees they would be those which had followed us to the place we were searching. It took Isherwood a month before he found a sitting specimen of *G. swynnertoni*, but once he had found one, he was able to collect them in large numbers. I believe that Dr. Nash found a similar initial difficulty in his studies of forest tsetse flies by this method. The fact that Isherwood found that his catches of females by this method approached 50 per cent. of the whole instead of the 5 to 10 per cent. taken on fly rounds showed that we were indeed dealing with a different population. Soon after this Jewell, Rennison and others, using first the ultra violet light method and later, painting the thorax with minute glass beads and searching with an ordinary torch, demonstrated that both *G. swynnertoni* Aust. and *G. pallidipes* Aust, which, during the day rested on the undersides of small branches, moved, at sundown, to the upper surface of leaves and returned to the branches at dawn. Recently Pilson and Leggate in Southern Rhodesia have been able to demonstrate changes, both at different times of day and seasonally, in the resting behaviour of *pallidipes* after feeding. Such studies are, of course, of the greatest value in showing where to apply residual insecticides.

There is not time to do more than mention the very valuable work of Bursell who, in the laboratory, has carried out a number of studies on physiology and behaviour which are beginning to explain such field observations and, incidentally, to suggest reasons why discriminative felling of bush sometimes fails to eliminate tsetse. I must, however, mention one paper by Bursell, because it opens up another field of study and relates geographical distribution to the phylogeny of *Glossina*. He has shown that the puparia of the forest dwelling *fusca* group, living in humid climates, are freely permeable by water, but that the savannah tsetse flies, the *morsitans* group, have puparial shells showing a high degree of impermeability. This over-simplification of an important study suggests that impermeability to water is one of the principal mechanisms which were developed when the *morsitans* group of tsetse flies evolved from the more primitive *fusca* group in response to a drying African climate.

I return once more to insecticides before leaving the subject to Mr. Hocking. In Southern Rhodesia we are faced with an advance of *Glossina morsitans* Westw. and *G. pallidipes* into a vast area of cattle ranches. Some 300,000 head of cattle are threatened. While we are organising various forms of land management which, we hope, will provide a permanent defence, it is vital to prevent local advances which may outflank us and we have to act very quickly. The system is as follows. All cattle within thirty miles of the fly line are subject to weekly examination when dipped against tick infestation. Any animal in poor condition has blood smears taken. Positives receive treatment with berenil, a drug which has no residual prophylactic effect. If there is a recurrence of infection in the herd it is assumed that tsetse are present. We begin surveys with bait cattle and the affected livestock are treated with prophylactic antrycide. At the beginning of the next hot season we undertake a discriminative insecticide campaign, with dieldrin sprayed from motorised portable machines, in those parts of the bush which are believed to be potential concentration sites of the fly. These sites have already been mapped on a scale of 1 : 20,000 from aerial photographs. In an operation last year we did, in fact, catch three tsetse flies before spraying began, but we should have sprayed if we had found none. The operation was completely successful, with an immediate disappearance of infection from the cattle on the ranch involved.

This operation illustrates two points. First, that without insecticide and drugs we should have been compelled to evacuate the cattle, to have instituted bush clearing or shooting schemes, which take from two to five years to become effective, against a fly front of about 150 miles long which has, not long since, been moving, in places, at a speed of about seven miles per annum: an almost impossible task. Drugs today enable us to hold cattle in the presence of tsetse and insecticides permit, provided one's vegetation surveys are sufficiently comprehensive, extremely rapid action. The second point is that the closest co-operation is now necessary between veterinarians and entomologists. When I first began work on tsetse flies one scarcely ever met a veterinary officer. They kept their cattle well away from the tsetse and treatment of disease made no contact with vector control. Today there are very few tsetse control departments left and most Veterinary Departments have tsetse control branches. Some people have felt uncomfortable about this, but I am sure it is a valuable step forward.

This leads to research on *Glossina* as a vector of trypanosomes. One peculiarity of antrycide and other, newer, drugs is that their efficiency as prophylactics is in inverse ratio to what has come to be called the " trypanosome challenge." Much of the practical approach to this problem has been developed by Whiteside, of the Kenya Veterinary Service. The trypanosome challenge he defined as the product of the apparent density of the local tsetse population and the frequency of infection as revealed by dissection of samples of the flies. More recently Robson and Hope Cawdery obtained a measure of the number of infective bites received by a single ox per day and from this estimated the rate at which infection should spread through an unprotected herd. Expectation and observation coincided closely. But in practice it would be difficult to work out challenge so precisely and Whiteside's rough approximations to high, medium and low challenge, checked against test herds, has allowed Kenya, and other countries, to pasture cattle profitably in tsetse infested bush at costs varying from less than a shilling per beast per year in low challenge to ten to fifteen shillings in high. We are thus, with cattle, approaching the situation of human trypanosomiasis in West Africa where the use of pentamidine as a prophylactic drug since about 1946 has greatly reduced the incidence of the clinical disease in populations living in contact with riverine tsetse.

Now one research problem posed is to define the factors which result in a particular level of trypanosome challenge. Thus in Southern Rhodesia we have to use drugs to keep cattle in areas where we can find no tsetse flies. In other words, tsetse density is so low that, measured by conventional methods, it is nil and therefore, the challenge measured on Whiteside's formula is also nil. The explanation, as we have now found, is that *Glossina* in the Zambesi Valley has an incidence of infection four or five times greater than tsetse in Central Kenya. Some years ago Burtt found that by incubating tsetse pupae at 30°C. he could infect the emerging flies with *Trypanosoma rhodesiense* much more easily than if he kept the pupae at lower temperatures. Fairbairn and Watson in West Africa have followed this up with a study of the development of *Trypanosoma vivax* infections in *Glossina palpalis* (R.-D.). Like Burtt, they found that high temperatures of pupa maintenance enhanced infection, but they also showed that this was further increased by keeping the adult flies at slightly lower temperatures. They suggested that the well-known seasonal cycle of infection in cattle, rising to a peak in the rains, resulted from tsetse which had lived as pupae through the very hot end of the dry season to emerge when the rains brought a fall in temperature. We have a nice example of this sort of thing in Rhodesia. In one area with low mean annual temperature cattle become infected in the rains, but in the dry season can be grazed very close to tsetse infested forest with hardly a case occurring. Twenty-five miles away, but 2,000 feet lower, where it is much hotter, cattle can only be kept, up to twenty miles away from the nearest discoverable tsetse, by continuous use of drug prophylaxis.

It is not to be supposed that temperature is the only controlling factor. In 1954 Dr. Jackson reported that Weitz's serological tests had shown that a majority of *G. morsitans* and *G. swynnertoni* fed on pigs. This work has been greatly extended. We know that generally these two flies use warthog as a principal source of food; that *G. pallidipes* and *G. longipalpis* Wied. often feed mainly on bushbuck, *G. longipennis* Corti on rhinoceros and, as expected in sleeping sickness areas, *G. palpalis* relies mainly on man, his domestic stock and reptiles. We also know that these most frequently chosen hosts may be replaced by other animals, for example, in one area in Western Uganda, hippopotamus is important to *G. morsitans* and there are several other anomalies. Probably with certain exceptions, it is the availability of the host which is important, that is to say, the way in which its habits fit in with the behaviour pattern of the tsetse. But one interesting fact is that certain animals, such as impala, hartebeest and zebra are seldom attacked, even when very abundant. This perhaps ties in with some work by Ashcroft, Burtt and Fairbairn who have shown that warthog and bushpig, both apparently favoured hosts, can only be with difficulty infected with *Trypanosoma rhodesiense*, show a very slight parasitaemia and then throw off the infection. But impala and various other antelopes, which may contribute little to the tsetse diet are easily infected and retain peripheral blood parasites for many months. Whether these same effects are to be observed with other trypanosomes we do not know, but it is likely. If so, the different immunological responses of the wild game animals are almost certainly interrelated to host choice in contributing to the level of infection in the wild *Glossina* and hence, of course, to the incidence of disease in cattle. This by no means completes the picture for Squire has related the level of infection in wild *palpalis* to the mean age of the population, while Wijers has shown that the same species is much more likely to acquire an infection if it feeds on an infected host during the first twenty-four hours of its life than later.

I have left out a great deal that is important, but I must mention three more subjects. During the period I have reviewed, Potts has carried out a very thorough investigation into the possibilities of using gamma-ray sterilised males as a means of tsetse control, a study suggested by the success of the method against the screw-worm *Callitroga*. Although the result was not promising as a practical measure, the work led to a necessary revision of preconceived notions about the mating of *Glossina* and stimulated effort directed towards the still not completely solved problem of the maintenance of tsetse colonies in the laboratory.

One of the most exciting events, of course, has been the isolation by Heisch and MacMahon of *Trypanosoma rhodesiense* from a wild bushbuck. This proved, at last, that wild game animals are indeed reservoirs of Rhodesian Sleeping Sickness and, incidentally, added weight to the idea that *G. pallidipes* is an important vector of the disease.

Finally, the use by Trager of cultured *Glossina* tissues to produce infective forms of trypanosomes *in vitro* has introduced a new technique which will certainly have important uses, among which, I would suggest, will be a study of the differences exhibited by various species of *Glossina* as vectors of trypanosomes and the influence of the tsetse fly in changing the behaviour of trypanosome strains.

I would like to end by pointing out that tsetse research has now turned full circle. Just before the 1914 war a Colonial Office Committee decided, against the protests of, among others, the great David Bruce, to put its money on eradication of the tsetse as the only solution to the problem, with the result that except in the *palpalis* areas of West Africa, the role of *Glossina* as a vector of disease was largely forgotten. Now, chiefly because of the discovery of antrycide, we are seeing the problem as it should be seen, as a single whole.

The Control of Tsetse Flies with Insecticides

By Dr. K. S. Hocking
Colonial Pesticides Research Unit, Arusha, Tanganyika

Suggestions for control of tsetse flies by chemical means must show some advantage, in cost or speed of action, over methods of control by total or partial clearance of the bush habitat of the flies. In all methods of control by insecticides, isolation of the tsetse habitat is essential for a permanent result as the habitat is not made unsuitable for the flies but not, of course, necessary if only a short term reduction in numbers is required—for example to stop a sleeping sickness epidemic.

Application by Aircraft

Some species of tsetse flies, such as *G. morsitans* Westw., *G. swynnertoni* Aust. and *G. pallidipes* Aust. in East Africa, occur over wide areas of country, often many hundreds of square miles in extent, and for the control of such species, the use of aircraft for the application of insecticide has obvious advantages, the chief of which is, of course, their ability to cover large areas quickly. Against the more confined riverine species such as some *G. palpalis* (R.-D.) ground methods of application are often adequate and much cheaper. Application from the air has been found to be uneconomic, even if possible, against species living in high forest, such as some *G. palpalis* and *G. brevipalpis* Newst. (Hocking and Yeo, 1953).

Savannah woodland, even if containing evergreen thickets, can however be successfully treated; though it is preferable that the leafless period of the year is chosen. The only effective applications have employed the insecticide in the form of a coarse aerosol containing as much as possible of its volume in droplets between five and fifty microns in diameter. Larger droplets are unable to bypass obstacles such as leaves and branches and penetrate to the resting sites of the tsetse flies and smaller droplets do not deposit very effectively on the insects themselves. Under tropical conditions, applications of coarse aerosols are effective only for a limited period (one or two hours) just after dawn and unreliably for an even shorter period before dusk. At other times, meteorological conditions are so unstable that rapid diffusion of the aerosol occurs (Yeo and Thompson, 1954).

Aerosols have been produced from aircraft emitting an oil solution of insecticide under high pressure through fine nozzles on an extended boom, by injection of the insecticide solution into the exhaust of the aircraft, or by various types of rotary atomisers. Injection into the exhaust system involves some decomposition of the insecticide by heat, which may or may not be important; fine enough droplets can be produced by the first method only if used on a reasonably fast aircraft, and the most promising equipment for aerosol production from light aircraft would seem to be the Micronair spinning cage produced by Messrs. Britten-Norman Ltd.

The first practical control of tsetse flies by applying insecticides from aircraft was in the Mkuzi Game Reserve in Zululand where repeated applications of exhaust-generated aerosols containing DDT made over several years succeeded in eliminating *G. pallidipes* and *G. austeni* Newst. (Du Toit, 1954). In East Africa, a suitable aerosol was produced from Avro Anson aircraft by emitting an oil solution of insecticide under a pressure of 150 lb. per square inch, through Bray nozzles pointing forwards, with an air speed of approximately 120 m.p.h. An effective procedure has been to use a 10 per cent. solution of DDT in oil at one quart per acre (1 litre per 0·4 hectare) with a swathe width of 50 metres. Eight such applications at fortnightly intervals have eradicated *G. morsitans* and *G. pallidipes* from a sixteen square mile block at a cost of about £1,000 per square mile (Hocking and Yeo, 1956) and radically reduced the tsetse population in other cases (Hocking, Yeo and Anstey, 1954). The fortnightly intervals were based on the need to kill newly emerged adult flies before they produced new larvae, and the eight applications were to cover two pupal periods. Experimentally, a 5 per cent. solution of either dieldrin or γ BHC in oil at a dosage of $\frac{1}{12}$ gal. per acre using an Auster aircraft, fitted with the Britten-Norman Micronair equipment has given high kills (over 90 per cent.) of adult male *G. morsitans* and *G. swynnertoni*.

Calculations by Yeo and Simpson (*Bull. ent. Res.*, in press) have shown that, with applications giving a 90 per cent. kill of adults, monthly intervals between applications should be more effective than two week intervals if the same number of applications are made, thus enabling a light aircraft to be used for larger areas. An attempt to eradicate *G. morsitans* and *G. pallidipes* from a twelve square mile block with $\frac{1}{12}$ gal. per acre of 5 per cent. γ BHC in this way was not successful, probably mainly because the kill of female flies was considerably lower than that of males and there was not therefore sufficient margin for contingencies, the kills being considerably reduced when, for example, meteorological conditions were not ideal or the spraying equipment was not working at full efficiency. The experiment repeated with $\frac{1}{8}$ gal. of 2·5 per cent. dieldrin per acre has however been very successful and at a much lower cost than when using $\frac{1}{4}$ gal. of 10 per cent. DDT, although the overall cost is still about £350 per square mile.

Ground Aerosol Machines

Under this head can be included machines such as the " T.I.F.A." and the " Swingfog " which use a blast of hot air to produce aerosols, and canisters which produce insecticidal smokes by the burning of combustible mixtures containing insecticides.

Experimentally, and on a limited scale, smoke canisters have been used with some success by C.P.R.U. against *G. palpalis* in Uganda and by E.A.T.R.O. against *G. swynnertoni* in Tanganyika (Crawford, 1949). The chief difficulties in their use are connected with getting adequate and uniform distribution of the smoke under varying wind directions and meteorological conditions.

Ground aerosol machines could compete directly with aircraft applications for the destruction of savannah tsetse species but would need a more elaborate organisation to cover an extensive area. The " T.I.F.A." has been used in Northern Rhodesia in an attempt to eradicate fly from twenty square miles of bush, the cost for insecticide being about £100 per square mile. The " Swingfog " has been tried in Rhodesia to prevent the carriage of tsetse flies by road traffic and in Kenya the " T.I.F.A. " has been used to disinfect trains in a similar way.

Residual Treatment of Vegetation

(a) In East Africa the riverine tsetse *G. palpalis* is apparently dependent on vegetation at the water's edge for its feeding area. Treatment of this vegetation with an emulsion of a residual insecticide, so that it remains lethal to the fly, on short contact, for more than a pupal period (say for two months) is generally sufficient to control this species and possibly to eradicate it. This method was developed by this Unit in 1948 (Woodcock, 1948) and adopted by Kenya as a control measure from 1951 (Wilson, 1953). The earlier control measures of this nature were carried out with 5 per cent. DDT emulsion applied at about 15 gal. per mile of river, four times at two-weekly intervals, which cost about £42 per mile. It was later found that 1½ per cent. dieldrin emulsion applied twice with a month interval, or 5 per cent.

dieldrin emulsion applied once, both at the same rate, were more effective (Burnett, Robinson and Le Roux, 1957). In Uganda the standard method is now to apply 5 per cent. dieldrin emulsion once only to selected portions of the riverine vegetation at a total cost of £20 per mile. These costs compare with an average cost of bush clearing on these rivers of £200–300 per mile, but are more than doubled by the cost of the necessary surveillance to determine whether any fly remain. In most of this control work the insecticide has been applied with knapsack or compression sprayers by labourers walking down the river bed, but in some larger streams a more effective method has been found to be application by a power sprayer from a punt which is poled down the river.

(b) A considerable amount is now known about the resting places of the savannah species of tsetse fly in East Africa, *i.e.*, *G. morsitans* and *G. swynnertoni.* In a block of fifteen square miles of isolated *G. morsitans* habitat in Uganda an experiment has been carried out where dieldrin emulsion was applied to the lower side of the branches of *Acacia hebacladoides* trees in fly concentration areas, these being the putative daytime resting places of the flies. The apparent density of *G. morsitans* was reduced by over 99 per cent. and the method, when applied over a sufficiently large area, would probably be effective in eradicating the fly. It cost about £250 per square mile.

In areas with a very severe dry season *G. morsitans* becomes an effectively riverine species, and in the north of the Northern Region of Nigeria, for example, where the relative humidity is down to about 5 per cent. for most of the day during several months of the year and the maximum temperatures are well over 100°F., this fly is confined during the heat of the day to the lowest part of the trunks of the well shaded trees along the river banks. Treatment of these places with residual insecticide, which is a comparatively cheap and rapid procedure, is sufficient therefore to eradicate *G. morsitans.* The Veterinary Department of the Northern Region of Nigeria is treating effectively areas of the order of 100 square miles in a season at a total cost of about £160 per square mile (McLennan and Kirkby, 1958). In places where the dry season is neither so prolonged nor so severe, more extensive treatment is required, but the method is still practicable.

Other Methods of Control

Attempts have been made to control tsetse flies by the use of treated traps and treated screens both in East and West Africa. Eradication has not been achieved, and is not likely, by these means, but they may have their use in the reduction of tsetse numbers in such places as river crossings and watering places in sleeping sickness areas, and thus reducing sufficiently the man-fly contact. Attempts have been made in Kenya to improve the efficiency of the method by the addition of attractants to the traps. If successful the development of attractants might also be of value in increasing the contact between the fly and treated stretches of vegetation, and present work by the Veterinary Department in Kenya gives promise of success with various animal extracts. Conversely, repellents might be of use in enabling cattle to cross narrow fly belts without acquiring trypanosomiasis.

An interesting control method which has been tried experimentally and shown promise is the use of insecticidally treated cattle as lethal bait for tsetse flies (Whiteside, 1949; Burnett, 1954). The main difficulties in the method are dispersing the cattle in such a way that a high proportion of flies contact them for food rather than the natural game hosts in the area, and also keeping the insecticide deposit on the cattle at a lethal level for a sufficient length of time. Attempts have been made to solve the second difficulty by feeding insecticides to cattle and thus making their blood toxic to blood sucking insects but this is not yet a practicable proposition. Recently experiments by E.A.T.R.O. in spraying cattle with very dilute emulsions of dieldrin have given very promising results.

Conclusion

To sum up; under suitable conditions, blanket applications of insecticide from aircraft or from ground machines can be very effective in eradicating tsetse flies and prove no more expensive than other methods. As, however, knowledge of the habits and behaviour of the various species of *Glossina* grows, the discriminative applications of insecticide to eradicate these species can be made more precise, more economical and more effective and this method of using the persistent insecticides would seem to be the most promising line for the future. Other methods of application, such as the use of sprayed bait cattle, may have their uses in special circumstances.

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Discussion

Opening the discussion, the CHAIRMAN said that he had been most interested in Dr. Hocking's account of selective spraying based on a study of the insect's behaviour.

MR. W. H. POTTS expressed doubts as to how far it was wise to depart from the original emphasis on the diminution of the vector in work on the tsetse, or, as it was now called, the trypanosomiasis problem. It might be true, he said, that because of that original emphasis the study of the relations of the tsetse to trypanosomiasis had been somewhat neglected, and that the balance needed to be redressed, but he thought it would be dangerous to regard the elimination of the vector as of only secondary importance. To be content with disease reduction, leaving the vector still in the field, with the continual expense of suppressing the disease, savoured too much of the payment of Danegeld to the enemy. Thus, although he welcomed the enlargement of the entomologist's horizon to which the Chairman had referred, he hoped that it would not lead to a neglect of those aspects of the work concerned with tsetse control.

He thought that the future envisaged by Mr. Ford need not involve that, for it seemed to him that the ideal plan of campaign could well be the use of the new methods of controlling the disease to allow of the early occupation of tsetse-infested country, and the employment of revenues from such use to institute a system of land usage that would produce conditions under which the tsetse could not continue to exist. He was encouraged in that hope by Mr. Ford's example of the way in which work against the encroachment of trypanosomiasis was now being carried on in Western Nigeria. He would, however, emphasise that for the evolution of such a system many aspects of tsetse ecology would require fuller knowledge than was at present available, and that such knowledge could only be obtained if attention was directed to the tsetse in its own right rather than merely as a vector. He referred to Mr. Ford's remarks on Bursell's work, and suggested that the mechanism acting as the basis for discriminative or spot clearing would not be understood without that ecological knowledge, and indeed that the application of methods that had worked well under one set of circumstances would need such basic knowledge for their application under another set of conditions.

MR. R. LAUGHLIN referred to Mr. Ford's remark that some animal hosts were attacked more frequently than others, and he wondered whether there existed the possibility of control with resistant varieties of cattle. MR. FORD replied that he did not know why some animals were less bitten by tsetse than others; he suggested possible differences in the behavioural patterns of the animal and the fly (as shown by Smith and Rennison), and also said that, although colour differences in animals had been shown to be associated with different rates of attack, the degree of infection was constant within a herd of animals of mixed colours. The CHAIRMAN remarked that some species of wild animals were certainly less bitten than others, and one of the commonest—the duiker—was left entirely alone.

Mr. R. C. Rainey asked if the speakers could give some information on the part played by micro-climatic factors in the biology and behaviour of the tsetse. Mr. Ford replied that any information on that topic tended to be fragmentary, but Bursell was working on the problem of the survival of *Glossina morsitans* Westw. in the Zambesi valley in the hot season, when screen temperatures were very high. As tsetse was killed after exposure for two hours in the laboratory at 45°C., it was possible that the fly created its own micro-climate. Edney was working in Salisbury on the effects of temperature control.

Mr. Ford, replying to an enquiry by Mr. D. J. Colwill on the methods used to apply insecticides to cattle, said that, although each species of tsetse was known to bite cattle at different sites, such differences were not taken into account and the cattle were run through a race or shower to give all-over cover. Mr. Colwill also asked for a comparison of the costs of bush clearing and game control with the cost of treating a typical square mile with insecticide in savannah country, which had been said to be about £250. Dr. Hocking explained that costs were very variable, but in general total bush clearing cost about £1,000 per square mile and game eradication was somewhat cheaper but offset by some disadvantages. From this, the Chairman asked whether Dr. Hocking did not think that some standardisation of costings was required. He suggested that the total cost of tsetse eradication per square mile should be itemised to include the cost of isolating the area to be treated, the cost of spraying and the " discriminative factor " or the ratio of the area actually sprayed to the area freed of tsetse. Both the first and last of these were very variable factors. If costs were thus detailed, the ambiguities in many accounts of tsetse control would be removed, for often it was not at all clear whether the expression " total cost " took into account the existence of, say, natural isolation or flies with very restricted habitats. Dr. Hocking agreed that cost standardisation was desirable, and that an account of field work should make it clear what items were included. His figures referred to the total application costs of insecticides to a given area, and isolation had not been included. Costs were increased when small areas had to be worked in which mobile hosts occurred, and also when, as was always essential for experimental errors to be avoided, isolation had to be achieved.

DISCUSSION ON DEVELOPMENT IN THE STUDY OF THE DISPERSAL OF INSECTS

Chairman: Dr. B. P. Uvarov, C.M.G., F.R.S., *Anti-Locust Research Centre, London*

The Chairman said that Miss Waloff and Dr. Johnson, the two speakers opening the session, would consider dispersal from the particular and from the more general standpoints respectively, but he hoped that the main contribution would be provided by the sum of experience of those present, and would be forthcoming in the general discussion which would follow.

The Fluctuating Distributions of the Desert Locust in Relation to the Strategy of Control

By Miss Z. V. Waloff

Anti-Locust Research Centre, London

Some thirty years ago, at the time when a plague of Desert Locusts, *Schistocerca gregaria* (Forsk.), was assuming serious proportions and threatening the agriculture of many countries, Dr. B. P. Uvarov first began the systematic assembly and analysis of distribution and migration records of this species. Over the years such records have provided valuable material for biogeographical studies by a number of investigators, and reference is made in this note both to the earlier published data, and to some recent analyses carried out at the Anti-Locust Research Centre by the author, Miss E. Betts and Miss J. Laszlo. Before dealing with this species, however, a brief reference must be made to two other plague locusts, whose biogeography has been studied at the Centre—*i.e.*, the Tropical Migratory Locust, *Locusta migratoria migratorioides* (R. & F.) and the Red Locust, *Nomadacris septemfasciata* (Serv.).

The plague of *Locusta*, which broke out in 1928, and in the course of a few years spread over some 7 million square miles of the African continent (Uvarov, 1933; 1933a; 1934) has been shown by cartographical and field investigations by O. B. Lean (1931, 1936) to have originated in a restricted outbreak area, less than 30,000 sq. miles in extent, situated in the flood plains of the river Niger in the Soudan Republic. Similarly the main outbreak areas of *Nomadacris*, which infested some 4 million square miles of the southern half of the African continent during its last plague beginning in 1930 (Uvarov, *l.c.*), have been shown by Allan (1931), Harris (1933), and Bredo (1938), to be restricted to two localities in Northern Rhodesia and Tanganyika, *i.e.*, Mweru Wantipa and Rukwa Valley, which between them cover less than 40,000 sq. miles. Subsequently, subsidiary outbreak areas of *Nomadacris* have been found in the Malagarasi plains in Tanganyika (Gunn, 1952), and, more recently, within the Niger outbreak area of *Locusta*, where populations of *Nomadacris* built up to a dangerous level in 1947 (Roblot, 1951) and again in 1959. The last major plagues of these two species came to an end in the forties, and all their subsequent outbreaks have been contained within the outbreak areas by the International African Migratory Locust Organisation and the International Red Locust Control Service, with headquarters at, respectively, Kara and Abercorn.

The plague dynamics of the Desert Locust, whose huge invasion area covers some eleven million square miles in Africa and south-western Asia, have been found to differ in some important respects from those of the other two species. Fig. 1 shows the year-by-year fluctuations in the number of territories infested by swarms of *Locusta*, *Nomadacris*, and *Schistocerca* during the period 1887 to 1958.* In *Locusta* and *Nomadacris* there had been only two major, and in both cases partly concurrent, plagues during this period, lasting some fifteen and eighteen years, and separated by plague-free intervals of about twenty years in the case of *Nomadacris*, and twenty-four years in the case of *Locusta*. A very different picture is provided by the graph of the Desert Locust infestations, which shows much shorter-term fluctuations, with peaks, in the last fifty years, in 1915, 1930, 1944 and 1953–55. With the gradual improvement in reporting, moreover, the troughs between the peaks have become progressively narrower and more shallow, indicating that swarms may occur in a considerable number of territories even during the recessions of the major plague. No fixed outbreak areas have been found for the Desert Locust, and it appears probable that one of the contributing factors to the rapid recrudescences of its plagues may be the building up of the gregarious populations which persist during the troughs. The possible importance in plague dynamics of such residual populations was first suggested by a French entomologist, Pasquier (1942), and our detailed examination of historical material confirms his hypothesis. Another mechanism of plague recrudescence, suggested by Stephenson and Rainey (in Rainey, 1951), may be the concentration by convergent air-flow of mobile scattered populations of ph. *solitaria* into areas which may become temporarily favourable for successful breeding and gregarisation.

From the systematic cartographical analysis of the Desert Locust records it soon became apparent that its infestations are markedly seasonal in nature over most of the invasion area. This characteristic is illustrated in Maps 1, 2 and 3, Fig. 2, showing the widely separated seasonal breeding belts in which Desert Locusts breed in the spring and in the summer seasons, and the very restricted area over which breeding occurs in winter. The close relationship between seasonal breeding and the rainfall regimes which has been discussed in a series of Anti-Locust Memoirs (Waloff, 1946; Donelly, 1947; Davies, 1952, and Fortescue-Foulkes, 1953) is further illustrated in Map 4, Fig. 2, which shows the rainfall regimes at some representative stations in the central and western parts of the invasion area, and the number of years, during the twenty-year period from 1939 to 1958 in which layings have been recorded in any given month within areas covering two one-degree squares containing and adjoining the station. It will be seen that on the Somali Peninsula, for example, the two laying seasons correspond closely to the two seasons of rain (*cf.* conditions at Belet Uen), while in the summer breeding belt running across the African continent to south of the

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* The graphs for *Schistocerca* and for *Locusta* are from, respectively, Waloff and Rainey (in preparation) and Betts (in preparation); the graph for *Nomadacris* is based on manuscript and published records on the files and in the library of the Anti-Locust Research Centre.

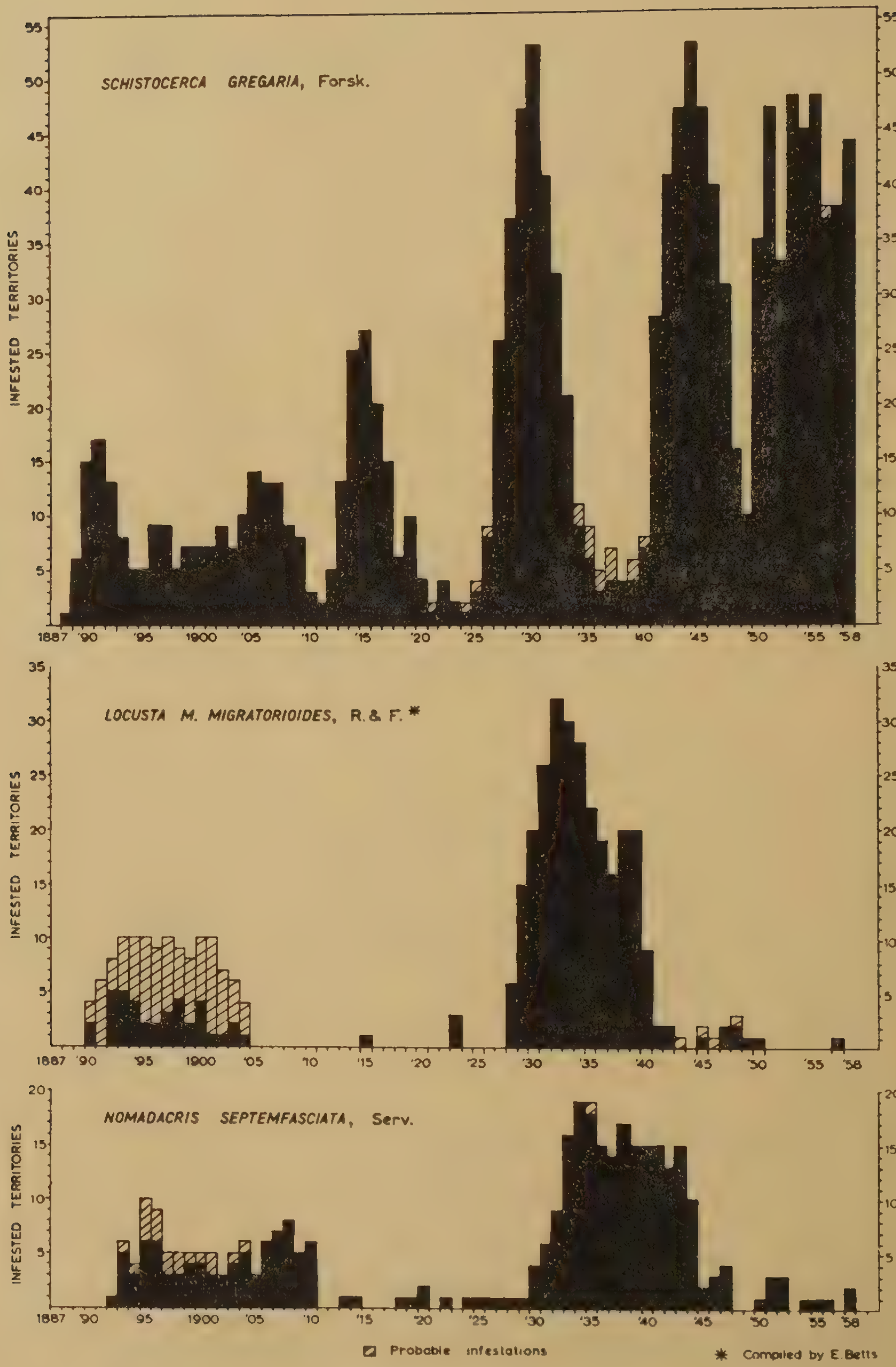

Fig. 1.—Year-by-year fluctuations in areas infested by swarms.

Sahara there is only a single laying season per year, coinciding with a single period of rains (*cf.* histograms for Boghé, Goundam and Khartoum). In central Arabia the single laying season occurs in spring, in accordance with the rainfall regime in that area (*cf.* conditions at Riyadh), while the incidence of breeding in winter, spring and summer, on the Red Sea coastal plain in the vicinity of Massawa is related to the incidence of rains in all these seasons in the southern Red Sea area. The close relationship between the rainfall and laying seasons is less apparent only near the northern margins of the distribution area—*e.g.*, in north-western Africa, where, in spite of the arrival of the swarms from October onwards, and the beginning of the Mediterranean winter-spring rains in the last quarter of the year, the maturation of locusts and the onset of laying are delayed for some months, probably by relatively low temperatures (*cf.* histograms for Marrakesh).

The seasonal occurrence is characteristic not only of Desert Locust breeding but of its infestations in general, for over most of the seasonal breeding belts the locusts lay soon after their arrival, and the newly formed swarms fly out of the areas in which they are produced soon after the locusts reach the winged stage. The transit areas between the widely separated breeding belts are traversed by long-range migrations, with swarms often covering distances of 1,000–2,000 miles, or longer, between their source areas and the areas in which they breed. As frequently recurring examples, may be quoted the movements of summer generation swarms produced south of the Sahara to the spring-breeding areas in north-western Africa, or in the Middle East, and the return migrations of spring generation swarms to the summer areas; other examples are provided by movements of winter swarms originating on the Somali Peninsula to the Middle East and Pakistan, or the migrations of summer swarms from India to Arabia and the Somali Peninsula. All parts of the invasion area may be linked (either directly, or with the intervention of a breeding season) by long-range movements, which bind its component parts into an immense, but essentially single, unit (Waloff, 1959).

Many of the seasonal movements have been found to agree with prevailing winds, and to change with them (Rao, 1942; Waloff, 1946), suggesting that the direction of swarm displacement is determined by wind; more recently Rainey and Sayer (1953) have demonstrated by aircraft observations on hour-to-hour trajectories of individual swarms that they moved directly down the corresponding mean wind between the ground and the height of the swarm. As could be expected from the downwind displacement of swarms, their distributions and movements were found to be closely related to current synoptic situations and wind-fields. In particular, as pointed out by Kraus (1958), the direction in which the newly-formed swarms move out of their source areas may often depend on the position, at the time, of seasonal low-level divergence areas, in which the outflow of air exceeds the inflow, and which form kinds of aerial " watersheds " from which air may flow in two opposite directions; for instance, the position of the winter divergence area which becomes established on the Somali Peninsula after the cessation of winter rains determines whether most of the winter swarms produced there will move southwards to Kenya and Tanganyika, or northwards towards Arabia. The ultimate destinations of the swarms, on the other hand, have been shown by Rainey (1951) to be areas of low-level convergence, in which surface winds show a net excess of inflowing air over the outflow, and which tend to be areas of precipitation, which is essential for the successful breeding of the Desert Locust in its mostly arid distribution area. Convergence areas of great importance in the annual cycle of the Desert Locust occur within the Inter-Tropical Convergence Zone when it is near its northern limit in the northern summer, and becomes a reception and breeding area for swarms produced in the preceding spring both to the north and to the south of this belt (Rainey, *l.c.*).

Since the seasonal synoptic situations in different parts of the invasion area are not identical from year to year, corresponding variations are shown by Desert Locust movements and distributions. The changes in the extent of infestation arising in the course of a plague are illustrated in a graph of month-by-month fluctuations in the number of one-degree squares infested by swarms and hoppers during the ten years from 1949 to 1958 (fig. 3A) and by the maps in Fig. 3B, which provide examples of widespread and restricted infestations occurring at the same seasons in different years. It will be seen that in addition to the long-term fluctuations illustrated in Fig. 1, the distribution of this highly mobile species is subject to continuous short-term changes, with the infested areas expanding and

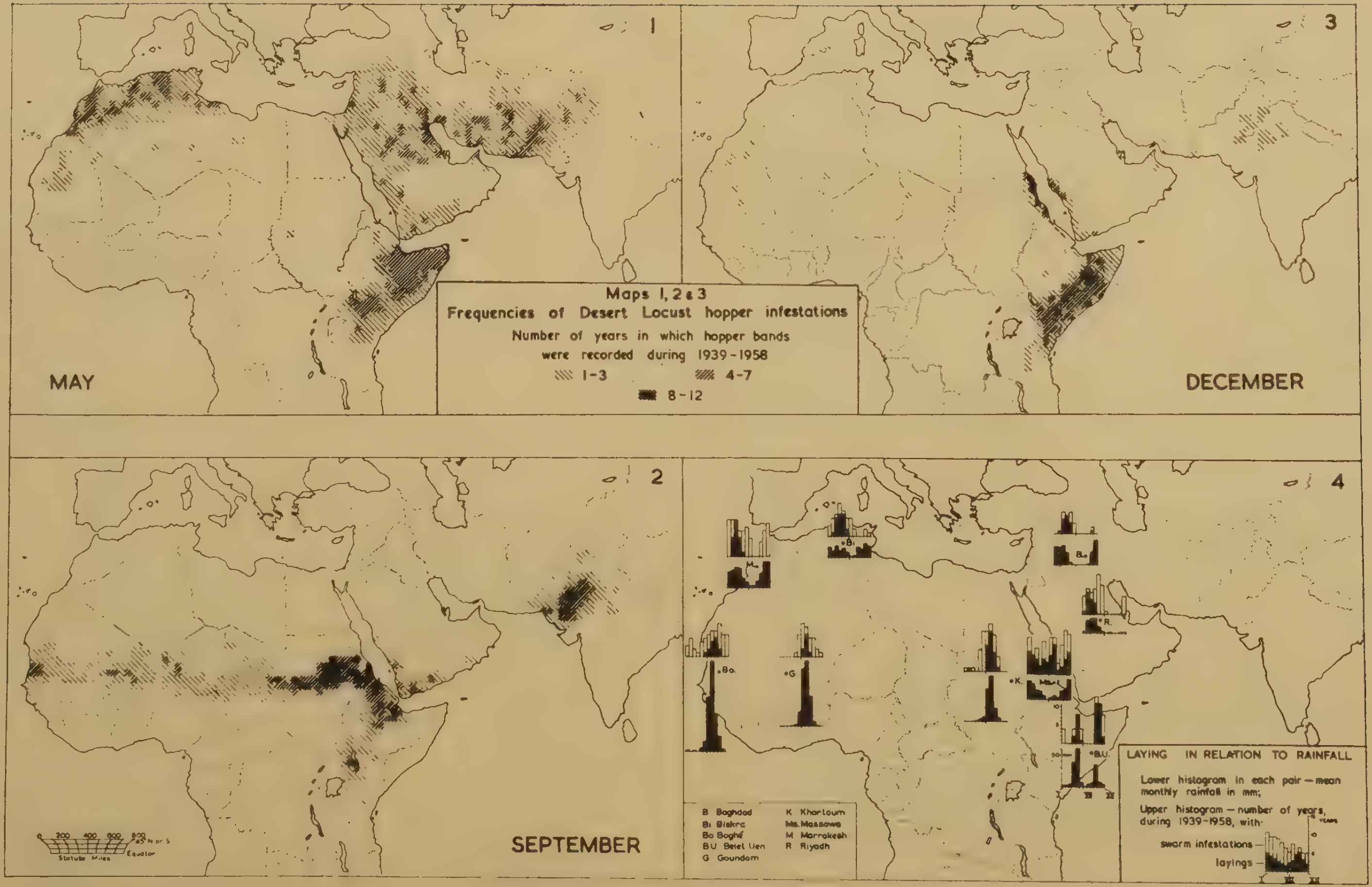
1
MAY
2
SEPTEMBER
3
DECEMBER
4
Maps 1, 2 & 3
Frequencies of Desert Locust hopper infestations
Number of years in which hopper bands
were recorded during 1939-1958
1-3
4-7
8-12
0 200 400 600 800 Statute Miles
23° N or S
Equator
B Baghdad
Bi Biskra
Bo Boghé
BU Belet Uen
G Goundam
K Khartoum
Ms Massawa
M Marrakesh
R Riyadh
LAYING IN RELATION TO RAINFALL
Lower histogram in each pair — mean monthly rainfall in mm;
Upper histogram — number of years, during 1939-1958, with:
swarm infestations —
layings —
years
I
VI
XII

Fig. 2.—Maps 1, 2, 3. Frequencies of Desert Locust hopper infestations. Map 4. Laying in relation to rainfall.

contracting with the seasons, and the seasonal distributions varying from year to year. Of special interest, from the practical point of view, are the occasions when the curves of the swarm and hopper infestations both descend to a low level, and the actual distributions show a compact pattern, indicating that the bulk of the swarming populations are temporarily concentrated in a relatively small area. Such a situation arose in the winter of 1951–1952 when the infested area was largely restricted to the Somali Peninsula—in contrast to the more typical widespread infestation at this season exemplified by December 1954; another example of a relatively restricted distribution is provided by the summer of 1956, in marked contrast to very widespread infestation in summer 1954.

Such marked variations in distributions raised the problem of relative liability to infestation of different countries invaded by the Desert Locust, and this aspect was investigated by the preparation of maps showing the frequency of infestations over a given period of time in different parts of the invasion area. This method appears to have been introduced by Cook (1929) in his studies of the infestations of the Army Worm, *Cirphis unipuncta* Haw., in the United States; in locust studies it was first used by Morant (1947) to illustrate the frequency of breeding in different parts of the Red Locust invasion area. For the Desert Locust the compilation of detailed maps of swarm and hopper infestation frequencies was begun in the fifties, after some fifteen years in which the reporting has been sufficiently reliable and uniform over the greater part of the invasion area; following a suggestion for which we are indebted to Dr. R. C. Rainey, these maps have been constructed with a one-degree square as the unit of area. Examples of monthly frequency maps of hopper infestations are provided by Fig. 2; other maps have been constructed for the swarm and hopper frequencies during each quarter of the year, and have suggested that the concentrations of large proportions of swarming populations into relatively restricted areas may occur particularly frequently during the third quarter of the year when swarms from different parts of the distribution area have moved into the summer breeding belt (Waloff, 1959).

It will have become apparent from the preceding remarks that the control of the Desert Locust presents very different problems from the control of *Locusta* and *Nomadacris*, and it may be useful, before concluding, to recapitulate briefly those aspects of its biogeography which appear particularly relevant to the strategy of control. Because of the great mobility of swarms and the wide geographical separation of the seasonal breeding belts, many parts of the Desert Locust distribution area are invaded by swarms from very distant sources, and in the majority of countries subject to invasions the first manifestation of a plague is the appearance of swarms originating some hundreds—or thousands—of miles beyond their boundaries. At the same time, owing to seasonal changes in the location of infestation most parts of the invasion area become seasonally free for periods of months even at the height of a plague, while the variations in the extent of seasonal infestations may, on occasion, result in the clearance of even high-frequency areas for periods of years. It follows that Desert Locust control organisations confining their resources to their own territories are likely to be occupied for only part of their time, and to remain idle while swarms which will invade them in the near future are being produced in another area, where control resources may be extended to the full and inadequate to cope with the infestation.

The rational control strategy thus appears to require the readiness by most territories affected by the Desert Locust to direct a large part of their control effort to areas outside their boundaries, and the creation of control units which could emulate the Desert Locust in their mobility. Only such an approach could make full use of opportunities provided by the high-frequency areas, and by those occasions when large proportions of the total swarming populations become temporarily concentrated into restricted areas, where their effective control could greatly modify, and even arrest, the further development of a plague.

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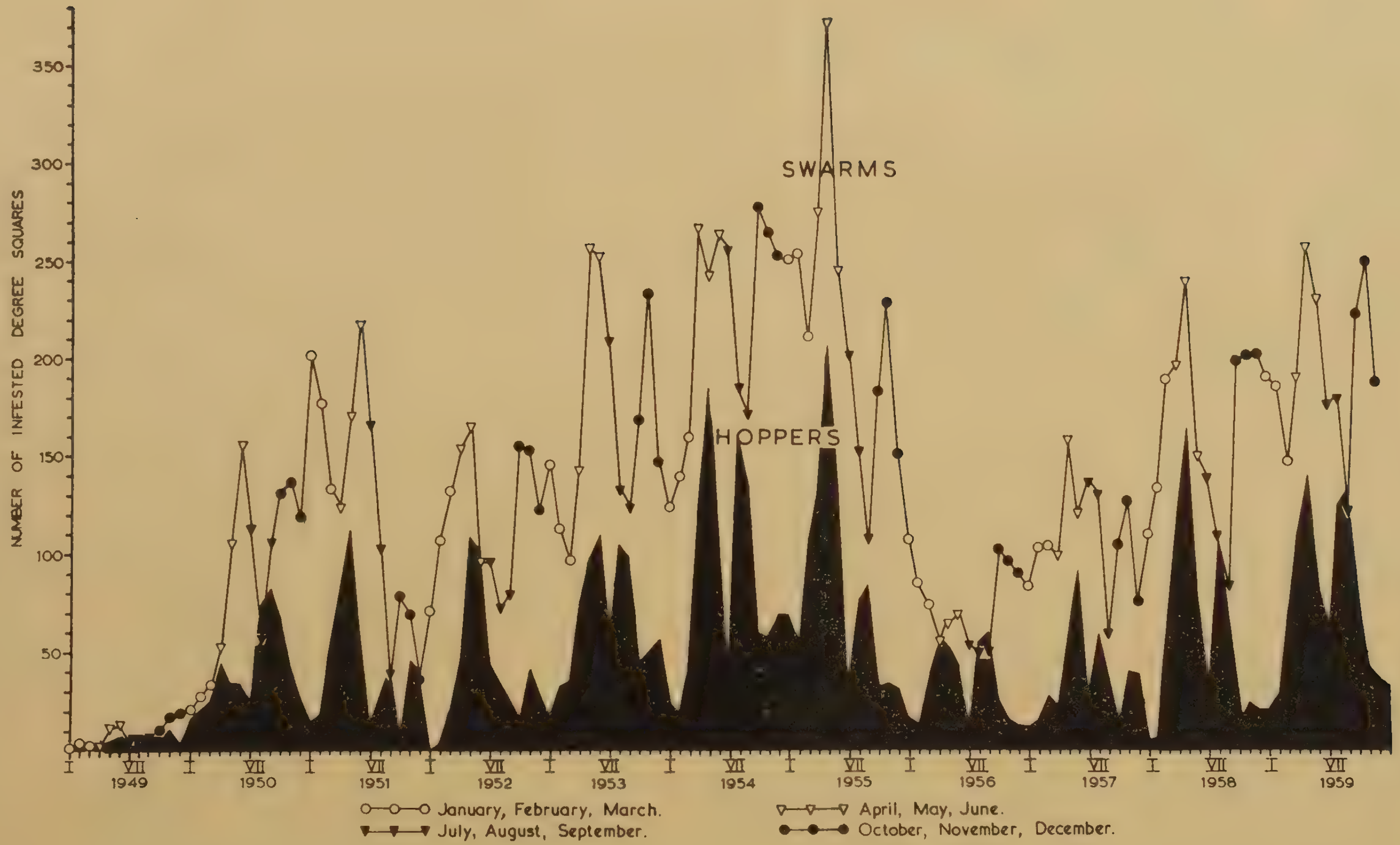

Fig. 3A.—*Schistocerca gregaria* Forsk. Month-by-month fluctuations in infested areas.

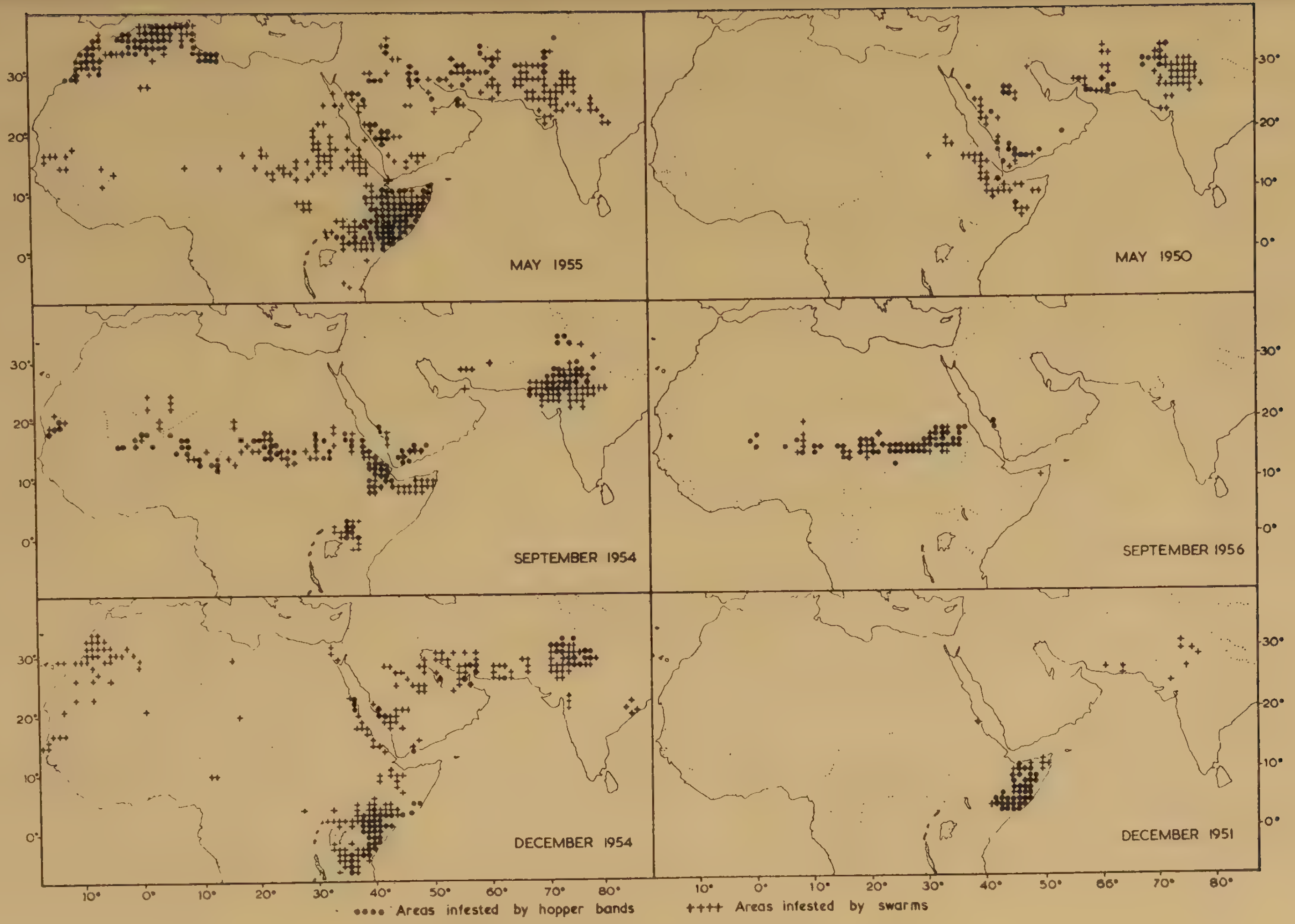
MAY 1955
MAY 1950
SEPTEMBER 1954
SEPTEMBER 1956
DECEMBER 1954
DECEMBER 1951
30°
20°
10°
0°
10°
0°
10°
20°
30°
40°
50°
60°
70°
80°
66°
•••• Areas infested by hopper bands
++++ Areas infested by swarms

Fig. 3B.—*Schistocerca gregaria* Forsk. Contrasts in distribution.

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The Present Position in the Study of Insect Dispersal and Migration

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Miss Waloff's paper dealt with a specific insect (the locust), large, strong in flight and moving in cohesive swarms across large areas devoid of breeding places. My paper deals with insects in general, most of which are small and weak, usually not cohering in swarms (though they may occur *en masse*) and which usually disperse within an area where breeding is ubiquitous and where horizontal displacement is therefore difficult to follow. There are of course a few species whose horizontal movements can be traced, but these are in the minority.

Hitherto dispersal has been seen as a rather haphazard, unorganised and accidental phenomenon in the general life of movement of insects and distinct from " migration " which often implies a movement, usually *en masse*, in a controlled direction.

There is little doubt that incidental dispersal occurs from movements associated with feeding, mating or oviposition: but there is also another specific kind of movement away from the breeding site by young adults which, far from being casual and incidental, appears to be an adaptation to secure an adequate spread of the species from its breeding site. Into this category come not only most classical migrations, but also many movements which, like those of Aphids, also occur *en masse* but are apparently non-orientated (C. G. Johnson, 1960). Once this specific exodus from the breeding site at a definite time in the life history is recognised, it becomes possible to think about constructing a long-needed functional system of migration and dispersal.

There are plenty of partial studies which have usually concentrated on displacement only, as with records of migration. But the whole process from the start at the breeding site to its finish in infestation or recolonisation, in both individual and collective aspects, has not been approached systematically because it has never been clear where or how " migrations " really begin.

The time now seems ripe to remedy this. This paper, which is not a review, sets out to do this and to describe the outlines of a general functional system of the migration and dispersal process without which a rational approach to problems of infestation can scarcely be made.

Migration and Dispersal

There have been many definitions of insect migration; they have generally stressed a common orientation with apparent control over the direction of displacement, or a " return " flight. Spectacular distances covered and mass movement have also usually been in mind if not actually made part of the definition.

These qualities of flight, however, seem to be special features and not a suitable basis for a general definition. Thus ants and termites fly but a few yards from old to new breeding sites; Aphids may travel hundreds of miles on the wind or only a few feet before finding a permanent host; locusts travel thousands of miles and many butterflies travel long distances in a common direction which is apparently under their control. The flight of each appears to have become adapted to the needs of the species and is a special characteristic: the only *general* feature is an undistracted flight away from he place of birth, usually expressed collectively in mass flights following more or less simultaneous emergence. " Mass dispersal " and " mass migration " (as well as the individual acts which contribute to them) are therefore to be regarded as similar phenomena (C. G. Johnson, 1960).

Past Approaches

Besides displacement, two other aspects of dispersal have often been studied. These are the changing numbers of insects in the air as shown by catches or traps, and the sudden appearance of mass "migrations." Consider first the changes in numbers flying. It is common practice to relate, by linear regressions or correlations, the variation in numbers caught in a trap to current weather changes. This is valuable for prediction though it does very little to elucidate the causes of aerial population fluctuations. Moreover in making this approach entomologists also make three assumptions that are not valid; (1) that the rapid response associated with weather factors is largely due to a variable ability on the part of individual insects in a population to fly; (2) that changes in aerial numbers can be reversed by changing weather, and that it is possible, so to speak, to move up or down the regression line with equal justification and facility; (3) that numbers of insects and weather changes are linearly related.

In fact, however, aerial density of insects changes not only because of vagaries of behaviour but because of extremely rapid population changes or rapid changes of locality. Attempts to distinguish " population " from " behaviour " by a running mean and periodic deviations from it oversimplify the situation and are unlikely to succeed. Moreover, population and behaviour changes are often irreversible, as when a sudden burst of emerging adults is followed by their permanent departure, and linear relationships are not common in this process, for flight is largely an " all or none " reaction and either does or does not occur above a certain temperature. Indeed, for a satisfactory analysis of aerial number change all the relevant biological aspects which contribute to a complicated sequence of changes during metamorphosis and adult life must be studied, each separately, and then put together again into a system as they appear to occur in nature. The best place to begin this is at the start of the process—*i.e.*, at the breeding site—whatever subsequent events may be.

Variations in Aerial Density at the Source

I suggest that the periodic, mass-discharge of alate migrants of *Aphis fabae* Scop. into the air at the breeding site illustrates the fundamental pattern of the beginning of other insect migrations, although the relative importance of one or another factor may vary with different species.

A suction trap over an infested bean crop shows that the numbers of *A. fabae* caught daily, rises to a maximum as the population grows and then declines to zero. This " flight curve," reflecting a population trend, is characteristic of migratory insects and its course is not correlated linearly with weather though weather influences it: in fact at a constant temperature a similar rise and fall could also occur.

The daily variations from the smoothed population curve also are but loosely correlated with current weather changes: even though the changes in numbers trapped from hour to hour are affected by the weather at the time (and might be expected to reveal weather controlled flight activity), this effect is quite obscured by other current events.

This apparent intractability in making correlations in the process which is obviously affected by weather is because the emergence of adults is rhythmic and not linearly dependent on temperature; the maturation of these adults is curvi-linear with respect to temperature; and their individual take-off is an " all or none " reaction to light and temperature, and tends to be normally distributed. There is a limited supply of adults during the day and its depletion as migration continues makes aerial numbers decrease in a way dependent on the rate of previous departures.

The hope of finding a consistent linear relationship of density fluctuations with weather factors is remote!

The Analysis of Periodic Exodus Flight in *A. fabae*

After moulting from the last larval instar the winged adult matures during the teneral period which ends in a departure flight, provided temperature and light permit. The maturation or teneral period varies with temperature and the amount of energy required to complete it is expressed, as the *thermal constant*, in hour-degrees centigrade. It is possible to estimate when an insect will accumulate enough hour-degrees during a period of known, but variable, temperature. Therefore if the emergence rate is known the flight curve can also be estimated, provided light and temperature thresholds are also known. In this way the complex and variable double peaks of daily flight in *A. fabae* can be analysed and reconstructed with considerable accuracy (Johnson, C. G. and Taylor, 1957; Johnson, C. G., Taylor and Haine, 1957; Taylor, 1957).

The basic elements of emergence, teneral development in relation to temperature and flight thresholds, are to the dispersal system what molecular weights, valency, and melting and boiling points are to chemistry. I suggest that entomologists need to measure these basic facts systematically for pest species; for without them systems of pest ecology will be stultified. Routine work is needed to establish such basic facts.

Displacements

There are many records of lateral displacement for Lepidoptera, frog-hoppers, Aphids, locusts, beetles and others. The origin and distance of the movement have occasionally been established by the associated wind trajectories, or by marking experiments. Sometimes to and fro journeys have been recorded although it is not always made clear whether both journeys are made by the same individuals or by those of another generation: frequently insects are spoken of collectively, as for example in making a return journey so as to impute to individuals behaviour which they do not possess. This applies also to vertical dispersal, for though the aerial plankton may exist all day, the flights of individuals contributing to the population may be of very short duration. The word " they" should be used with care and qualified as relating, specifically, to individuals or in general to groups. A species may alternate between two habitats without individuals making more than one flight.

Where dispersal occurs within a large breeding area and lateral displacements are difficult to trace, much can be learned about movement from studying the vertical dispersal.

It is commonly thought that the " aerial plankton " is made up of small, weak insects because they are more easily blown about than large, strong ones. Nevertheless the displacement of all insects, even the strongest, depends a great deal on the movements of the air masses within which these insects fly (*e.g.*, locusts) and a flying insect of any size or strength is in this respect weightless. I suggest that small insects predominate in the " aerial plankton " because of their overwhelming commonness compared with large species and because the flight away from their breeding sites at least is adapted to ensure a considerable displacement by moving air masses.

The character of the migratory flight after take-off is very important: there are enough records now of the flight of insects from breeding sites—ambrosia beetles, Heteroptera, Aphids, moths, dragonflies—to suggest that this departure is usually positively phototactic and takes the insect quite high into the air before wind, or directional flight, or both, ensures lateral displacement. The habit of flight at the exodus combined with the time of day when most individuals make this flight are probably more important than " buoyancy." When aerial travel is passive, as with spiders or the gypsy-moth larvae, buoyancy is obviously the important thing: but where flight is active, time and character of flight may be the significant factor. Much of the early work on the aeroplankton in America stems from work on wind-borne dispersal of gypsy-moth larvae and this may inadvertently be responsible for the early distinctions between so-called " passive drift " as distinct from " active migration " of *flying* adult insects—a view which detracts attention from what J. S. Kennedy (1951) long ago pointed out, namely the very active nature of even weak flight.

The Vertical Density Profile

Earlier workers on vertical dispersal—Glick, Hardy & Milne, Freeman, Berland—tried to correlate aerial abundance at heights up to several hundreds or thousands of feet, with weather factors: we have abandoned this approach for reasons already given.

The *total number* of insects in the air, as already shown, depends on how many leave terrestrial habitats; but the relative abundance at different heights, irrespective of absolute numbers, depends on the species, flight behaviour, periodicity, flight duration and the rate of take-off as compared with the rate of landing, and, particularly, on the degree of atmospheric stability.

This complex process of vertical diffusion produces a vertical density profile which, far from being capricious and although subject to the vagaries of wind and weather, can be formulated precisely and described succinctly and quantitatively in the single parameter λ, which is the regression coefficient of a linear transformation of density on height. This applies to all the data so far gathered by various workers (C. G. Johnson, 1957 *a*; Taylor, 1960).

The value of λ decreases as relatively more insects reach high altitudes and increases if the population accumulates in the lower layers of the air. λ is correlated with atmospheric stability (temperature lapse rate) (C. G. Johnson, 1957 *b*) and it varies with season. This does not mean that insects behave altogether like inert particles for then log density would be linearly related to log height over the whole scale, and this is not so. Insects take-off on their own account with excess of lift which is eventually lost; and they may, also unlike inert matter such as smoke in experiments on turbulent diffusion, land and take-off many times.

The profile is a dynamic system in which individual insects are constantly changing relative positions, horizontally and vertically, although the shape of the profile may remain constant. Its daily build-up and decay under various weather conditions and biological circumstances is a very important aspect of the dispersal picture for from it we may be able to deduce flight durations and the degree of lateral displacement.

The Balance Sheet or Interchange between Aerial and Terrestrial Populations

It is important in population studies, whether of aerial or terrestrial populations, to measure absolute density—*i.e.*, nos./unit volume of air or nos./unit area. Techniques of sampling such as with light traps fail to do this and are of limited help in constructing a quantitative balance sheet of terrestrial-aerial interchange.

Suction traps measure aerial density directly and the integration of the vertical density profile gives an estimate of the total number of insects in the air between any two heights. This is a step towards constructing the relation between aerial and terrestrial numbers. It is not sufficiently realised how the scales of aerial and terrestrial densities compare, because of a dearth of comparable, absolute measurements. But insects at a very high aerial density and occupying a large volume of air can be compressed into a very small habitat. For example, a very heavy infestation of *A. fabae* may discharge from one to ten million Aphids into the air each day, from one acre of beans. One to two million airborne Aphids would give a " mass migration " of high density over an area of five square miles to a height of about twenty-five feet.

Conversely, Aphids which Elton (1925) recorded on the snowfields in Spitzbergen (one every thirty–forty yards) 800 miles from their source and which he estimated to run into many millions, if put into the air would be only about one fiftieth of the lowest density we can measure with our largest suction trap—a mere whisp of what was probably no more than a fairly large migration.

Elton's Aphids were probably exceptional only in the distance they travelled—or perhaps even only in that such migrations are seldom observed! The vast majority of Aphids daily transported in the air over England in summer, at moderate densities finish their individual flights in a relatively short time and probably are dispersed over distances of within 100 miles. However, a small proportion may travel much further and, although at very low densities, may be deposited in enormous numbers though spread relatively thinly.

Any discussion of exceptional dispersal must obviously be qualified by these considerations. The question " How far can an Aphid travel? " like the question " How long is a piece of string? " has no simple answer: a more appropriate question is " What is the diminution of density with distance from a source with a known rate of output, under specified conditions? " This is a difficult question which as yet cannot be fully answered.

Repetitive Flight and Changes in Individual Behaviour During the Life History

So far I have given considerable weight to the initial migratory flight from the breeding site and to the displacement which follows, but there are also repetitive flights that in numbers and distance depend on species and circumstance. Some species have a very short flying life of minutes or hours, limited by wing muscle autolysis (ants and some Aphids respectively), whereas others live for months and continue " migrating " after hibernation (*Eurygaster*, *D. plexippus* (L.)).

Obviously contributions to aerial density of insects of the aerial plankton depend on the number and quality of repetitive flights and so make it possible that weather-controlled flight behaviour plays a part along with the contributions made by the primary exodus flight.

Little is known about individual flight behaviour after the initial exodus even in a few species, though there is much invalid assumption. Few individual insects have, in fact, been followed in flight for very long, not so much in distance as during the individual life. There are indications that the character of flight changes with age, as reproduction and feeding activities obtrude, but the contributions made by such flights to dispersal are unknown with any species.

There is great need for research on the chronological changes which take place in the field during the lives of individuals.

The profound changes in phototactic response with age as shown by *Aëdes taeniorhyncus* (Wied.) (Provost, 1952) and by ambrosia beetles (Perttunen, 1959) are particularly significant for migration studies. Nor should it be thought that flight itself is merely a means of locomotion; migratory flight can also be a trigger setting off changes in reproductive behaviour and host selection, which in their turn modify behaviour (B. Johnson, 1955).

It seems to me that the greatest difficulty in present day dispersal studies lies in following the chronological sequence of changes in individual behaviour as the insect ages, and to do this often enough to ensure statistical reliability, covering average and exceptional insects. J. S. Kennedy (1956) has made a move in this direction with his flight chamber.

Without such studies the collective aspects of ecology and epidemiology can never be fully understood and always liable to the errors which arise when events at two levels of organisation individual and collective are interpreted as if they were subject to the same laws.

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Discussion

The Chairman said that he would like to hear views on the suggestion that the strategy of control should be concentrated in areas where temporary populations occur. FAO had been trying to take action in such regions, but it had been found that there was a strong tendency for individual countries to prefer to sit and await the outcome. Most of the countries appeared to be indifferent as to the sources of locust infestations. Mr. W. E. H. Hodson enquired whether small countries asked for assistance when an infestation occurred, and Miss Waloff confirmed that there was considerable international co-operation, particularly in the control of the Desert Locust, but in East Africa conditions were a little different as there was a regional organisation sponsored by FAO. Dr. O. B. Lean supported the emphasis that had been placed on adapting international Desert Locust control strategy to the seasonal plague displacements. There was, he said, a definite move in that direction in the Arabian peninsula and in Northern and Eastern Africa, and it was important that research should be similarly adapted.

Professor G. C. Varley referred to the work carried out in Canada by R. F. Morris [1959, *Ecology* **40**; 580–588], in which key factors responsible for variants in mortality (and thus of large population changes) could be identified, and wondered whether such information could be applicable to locust mortality and used in the prediction of locust outbreaks. Miss Waloff replied that some work along those lines had been done. The main factors were without doubt climatic, and lack of rainfall was invariably followed by a regression, yet other factors essential for success in prediction of the type mentioned by Prof. Varley had not yet been identified, so that the use of graphs in forecasting outbreaks failed in three out of four cases.

Dr. H. R. Lillie, speaking later in the session, said that locust swarms were unknown in Australia until 50 or 100 years after Captain Cook's landing, and speculation on the causes of the change in the habits of the locust ranged from the destruction of forest cover to the absence of birds, as presumably had happened in the Middle East in pre-Biblical times. Evidence from Queensland showed that in the past the bustard, emu and ibis had gathered at hopper-hatching areas and consumed their own weight of hoppers each day, but nowadays those birds had been almost wiped out in Australia. He wondered if Miss Waloff could say whether the onset of Desert Locust swarms in Africa could be attributed to the action of man in destroying forest or other habitats of predatory birds. Miss Waloff replied that there was no indication that fluctuations in bird populations were responsible. Work had shown that small numbers of locusts in Somaliland and the Red Sea area were controlled by birds, and the European Stork was predacious on swarms, moving with them during migration, but their effect on swarms measuring perhaps fifty square miles and containing astronomical numbers of locusts was negligible. The value of predators would be most marked when the hoppers were very young.

Dr. Peggy E. Ellis said that predators attacked desert locusts, but they were satiated by the vast numbers present and it was impossible to assess the degree of predation in individual instars, although the relative losses due to predation were higher amongst young nymphs than amongst older nymphs or adults, when locust populations had been reduced by the failure of the rains for several successive seasons, predators had concentrated on the few locusts present and visibly reduced the population. The CHAIRMAN commented that, in Australia, over-grazing by sheep was the main factor responsible for the swarming of locusts.

DR. J. RAWNSLEY gave an example of the value of a study of the ecology and behavioural pattern of a pest in its control. In Ghana, bagged cacao beans were stored in sheds, and became very heavily infested by *Ephestia cautella* (Wlk.). It was found that peak emergence occurred between 3 and 4 p.m., with the adults flying at 5.30–6 p.m. and then mating. This information has been put to practical use by sealing the eaves of the sheds and fogging at dusk every evening, so that the pest was now only rarely encountered in the port sheds. The factors operating at dusk included a drop in temperature, with increased humidity and, of course, darkness, and if one vital factor could be identified then its control would probably obviate the need for chemical measures. DR. JOHNSON was interested in the account, for he had known of the work and was glad to learn that it had been successful. He interjected the information that suction traps provided the most reliable means of determining the aerial density of insect populations, and that, although Rothamsted did not supply such traps, if an order for fifty or more was received it could be dealt with.

MR. M. E. SOLOMON enquired whether the proportion of an aphid population present in the air was dependent on the density on the crop below it, and whether any significant proportion of those that ascended came down again on the same crop or whether they represented a loss unrelated to the density on the crop. DR. JOHNSON said that his figures related to Aphids ascending from one acre; very few of them returned, if any, and their numbers were not related to population density, for initial flights of that nature were not induced by population pressures.

PROFESSOR V. B. WIGGLESWORTH said that the Garden Chafer, *Phyllopertha horticola* (L.), according to Milne's observations, had mating as its first activity after emergence, and that migratory flight only occurred later in a sporadic fashion. DR. JOHNSON replied that mating itself was a factor, and that females migrated only if they had not met a male.

DISCUSSION ON RESEARCH ON LOCUSTS AND THEIR CONTROL

Chairman: DR. J. W. C. GEYER, *Chief, Division of Entomology, South African Department of Agricultural Technical Services*

The CHAIRMAN said that the speakers were too well known to require any introduction. Dr. Haskell would be discussing locust physiology and behaviour, and Dr. Rainey would be dealing with operational research: he then called on Dr. Haskell to read his paper.

Physiology and Behaviour

By DR. P. T. HASKELL
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It is manifestly impossible in a paper of this length to attempt to cover the trends in locust research relating to all pest species. The most that can be done is to select for comment those areas of research and methods of control which seem most important at the present time and most promising for the future. You have already heard in Miss Waloff's paper this afternoon a summary of present knowledge of the distribution in space and time of three of the most important locust species afflicting the African continent, and the fundamental difference between locusts like *Locusta* and *Nomadacris* with restricted outbreak areas and *Schistocerca* without any such limitation, has been emphasised. This conception we can take as a starting point for our discussion. The basic strategy of counter measures in the case of *Locusta* and *Nomadacris* has been and will continue to be control of populations in the outbreak area to prevent escape of swarms. This control is carried out by chemical methods, a fundamentally unsatisfactory technique forced on us by the need for immediate palliative action and by our lack of detailed knowledge of locust biology. But in relatively restricted outbreak areas of the type referred to above, the possibilities of biological and ecological control are obvious.

At first sight biological control seems a poor starter. Comparatively little is known about vertebrate or invertebrate predators or parasites of locusts, although the experience of Lea (1958) in South Africa with the Brown Locust and Smith and Popov (1953) and Hudleston (1958) of the Desert Locust Survey in East Africa indicates that birds may be a major controlling factor over small areas and with small concentrated populations. In Eastern Africa, Greathead (1958a, b and c) has worked on various dipterous parasites of *Schistocerca*, such as *Stomorhina* and *Blaesoxipha* which again in certain areas and seasons produce a high degree of mortality and research on these lines has recently commenced for the Red Locust (du Plessis, 1960). We know of several bacterial, protozoal and fungal diseases fatal to locusts; artificial introduction of one of the bacterial diseases has been tried in the field with unpromising results (Stevenson, 1959). But further work on all these lines and the greater insight in locust biology which this will bring must not be neglected.

In restricted outbreak areas, ecological control is a potentially promising line and research in this sphere has been pursued by the International Red Locust Control Service in Central Africa, where fire-control, cattle ranching and tree-planting schemes have been tried and flooding has been investigated. The experience gained has shown that such schemes for critical assessment need in themselves an application of finance and research, and knowledge of locust biology, not at present available. But useful data have accrued; fire-control, for example, can be used as a means of concentrating oviposition and hence facilitating later chemical control of hoppers. It goes without saying that ecological control must be based on ecological research; in locust work this term has been interpreted in its widest sense and comprises investigations of locust numbers, distribution and behaviour in relation to the structure and vegetation of the habitat. The work of Gunn, Vesey-Fitzgerald and Symmons on *Nomadacris*, Davey on *Locusta* and Popov, Stower and Hemming on *Schistocerca* springs to mind; and mention must be made here of the F.A.O., U.N.E.S.C.O. Desert Locust Ecological Survey, now financed for the next five years from the U.N.O. Special Fund Project for Desert Locust Research.

But ecological and biological control does not produce results quick enough and chemical methods thus remain paramount; and with the Desert Locust, with its enormous invasion area and extreme mobility it is difficult on present knowledge to see any alternative to chemical control. Success with chemical control depends on many factors and as in many locust campaigns, particularly those against the Desert Locust, resources of men, money, machines and materials are too slender for the job in hand it is essential that operational efficiency be as high as possible. It is essential for adequate planning and logistics to have some indication of the size of the enemy and in this direction research has provided some population forecasting methods of reasonable accuracy for two species of locust. For the Red Locust Symmons (1959) calculated a regression equation relating parental and filial populations to the previous season's rainfall and also to the amount of rain at the time of egg-laying in the current year; the equation gives a multiple correlation of $R=0{\cdot}93$ $(P<0{\cdot}01)$. The practical form of the equation, giving an error of estimate of 0·55 unit on the arbitrary scale of infestation levels,

is $y = 6{\cdot}518 - 0{\cdot}160x_1 + 0{\cdot}425x_2 + 0{\cdot}92x_3$

where y = adult locust population in mid dry season on an arbitrary scale

x_1 = mean rainfall, in inches, of the Rukwa Valley and drainage basin during last but one wet season

x_2 = infestation level of parental (breeding) population on arbitrary scale

x_3 = the rainfall of Rukwa Valley, in inches, in preceding October-December.

The application of the equation in 1957 and 1958 has enabled the size of adult populations in those years to be forecast with consequent great saving of money on the related hopper campaigns. For the Brown Locust *Locustana pardalina* (Wlk.) Lea (1958) has found a somewhat similar relationship between abundance and rainfall, though the data were insufficient to calculate an equation. The point of such forecasts of numbers and those of possible movements of swarms such as are provided by the Desert Locust Information

Service of the Anti-Locust Research Centre, sponsored by F.A.O., is to enable chemical control campaigns to be realistically planned and implemented.

Chemical control of locusts can be considered under three main heads: baiting, dusting, and spraying. Baiting is still probably the most widely used method and with good conditions, utilisation of insecticide is high. It has the advantage of using unskilled local labour but suffers from two main disadvantages—the high cost of application resulting mainly from the high price and cost of transport of the carrier material, and rather variable toxic action. Dusting is still widely used and is advantageous in cutting transport costs and, by comparison with wettable powders or similar concentrates, in its economy of water consumption in arid areas, but it is difficult to apply and unreliable in action. The advantage of water economy is nowadays offset by the availability of oil concentrates. Low-volume spraying with oil concentrates of insecticides, a method now increasingly used, would seem the method of choice for the future; the cost of transport and application are low, toxic hazards to men and plants are no higher than with other forms of control and results, on present evidence, seem more reliable. The type of insecticide used and the method of application will naturally depend on the species to be attacked, its biology and its habitat and it is because of the need for increased operational efficiency in relation to the interplay of these factors that research on locust physiology and behaviour is essential to control. Data from control operations of all types for which adequate assessments are available indicates that it is in the behaviour of the locusts and not malfunctioning of equipment or unreliability of insecticide that the key to variability of efficiency is to be found. To illustrate and emphasise this point I shall in the remainder of this paper try to survey some of the factors involved in the use of low volume ground spraying against bands of locust hoppers.

In attacking locusts in this way, the method used can either be " target " or " barrier " spraying (Sayer, 1959). " Target " spraying refers to operations in which one or at least very few bands are directly attacked, either by spraying contact insecticide on to the locusts or by spraying vegetation just in front of them with a persistent insecticide which kills by stomach action when the locusts eat the poisoned plants. " Barrier " spraying also involves the laying of a swathe or barrier of persistent stomach insecticide, but in this case the barrier is laid not necessarily even in sight of hopper bands, but across a known infested area, on the assumption that hopper bands will cross the spray barrier within the period of persistence of the insecticide and be killed. It is clear that the method adopted will largely depend on the amount of information available as to the nature and extent of the infestation. If the bands are not numerous and their location known and accessible, target spraying can be adopted; if the bands are numerous, or the area of very large extent, barrier spraying can be expected to be much more efficient. If the area is very large and the infestation high it may be more economical, or if the terrain is impassable to vehicles it may be necessary to lay the barriers from aircraft. This latter method is in use on a large scale by the French G.A.L.A. organisation in West Africa (Mallamaire & Roy, 1959).

The importance of information in relation to the planning of control is enormous and it should be obvious that the use of aircraft, which can both reconnoitre and spray, may be very advantageous particularly in the case of species such as the Desert Locust with large invasion areas and highly mobile populations.

But whatever tactical method is employed, it is clear that the method makes various assumptions about the behaviour of locusts in relation to the spray barrier; these are, in logical order, first, that they will reach it and march through it, second, that they will feed on it, and third that they will consequently be killed. Are these assumptions justified, and if not, what can be done about correcting them? In view of the fact that locusts *are* killed by spray barriers, clearly for some of the locusts some of the time the assumptions are justified and it is therefore preferable to view the situation in the light of the desired efficiency of the whole operation and consider the basic problems to be answered to give this desired efficiency. These basic problems are as follows: first, each barrier must be of such a width and in such vegetation and with an insecticide deposit density such that the hoppers will get a lethal dose while marching across it. Secondly, the minimum number of barriers must be laid in an area and these barriers must be correctly aligned, so as to ensure (ideally) that all hopper bands reach them during the period of persistence of the insecticide. Various limiting factors in relation to the first requirement are at once obvious; it is clearly useless to lay barriers in the absence of vegetation, in vegetation which hoppers do not eat or through which they will not march. Beyond this we come on to what may be called the basic complex of factors; these are the deposit density of insecticide on the vegetation and the amount of food eaten by hoppers during passage across the barrier.

The LD 99 of dieldrin for fifth-instar hoppers of *Schistocerca gregaria* (Forsk.) is about 5 μg/gr. body weight or about 10 μg for an average hopper. Information on rates of feeding of this species is meagre but field data of Ellis and Ashall (1957) with caged locusts indicate an uptake of about 10 sq. cm. of leaf per 24 hours as a maximum rate. Thus a deposit density of 1 μg dieldrin for each cm.^{2} leaf surface is necessary to give an uptake equal to the LD 99 in 24 hours. Data again from Ellis and Ashall indicate possible average rates of movement of Desert Locust hoppers of about 25 yd./hr.; in the twenty-four hours necessary to take up the lethal dose the band may move 600 yd. Thus, as an example, a 600-yard-wide swathe with deposit density 1 μg/cm.^{2} leaf surface might be considered on theoretical grounds an appropriate barrier. The machine used in most trials with this method of hopper control has been the Sayer exhaust sprayer (Sayer & Rainey, 1958; Sayer, 1959) a simple, robust and efficient ultra-low volume sprayer worked by engine exhaust back-pressure. The physics of spraying with this machine have been investigated in reasonable detail (Sayer, 1959; Courshee, 1959; MacCuaig, 1960). Naturally the swathe width depends a great deal on environmental factors, particularly wind; all that need be said here is that an exhaust sprayer can produce deposits in excess of the required minimum over a swathe width of about 150 yards.

Laboratory work has shown that there is apparently no detoxication of dieldrin by locusts so that successive spray lines of this insecticide giving rise to cumulative toxicity could well have lower deposit densities, provided the parameters of food uptake and speed of movement remained the same.

But the average food intake per hopper may well be, and probably is, less than that quoted, so deposit density must be increased. How far can it be increased (a) economically, (b) before the insecticide or its carrier has any repellent effect on the insects and (c) before phytotoxic effects and other hazards occur? The answer to the first question is a factor in operational research. The answer to the last, on present evidence, is that the insecticides at present in use do not give rise to above-average toxic hazards to man, animals or vegetation at dose rates between two and six times greater than that normally required to kill locusts (Sayer, 1959).

The answer to the second question is not known, but research on the problem is being undertaken by the Anti-Locust Research Centre in the laboratory now and will start in the field in Africa this year. Experiments in a special behaviour apparatus (Haskell, Paskin & Moorhouse, unpublished results, 1960) have already indicated that *Schistocerca* hoppers are attracted to grass over distances of at least 4 feet by olfactory stimulation and work on attraction and repulsion is proceeding; it may be possible to add attractants to the insecticide in order to increase feeding time and rate of intake in the barrier and to offset any possible repellent action of the chemicals. In relation to studies of attraction and repellence it is necessary to know something about feeding and food plant preferences of locusts and the possible existence of phago-stimulant or phago-attractant factors in relation to this behaviour. A laboratory study of locust nutrition sponsored by the Centre and carried out by Dadd at Imperial College has resulted in the accumulation of interesting data in this respect—and also in the production of an artificial diet for locust breeding, an important adjunct to laboratory experiments in this sphere (Dadd, 1960). An interesting aspect of further research on these lines now being pursued at the Centre is that hoppers fed entirely on artificial diet from emergence will not eat grass as adults and have to be forcibly fed on it. This seems to indicate the existence of some learning behaviour, which may be important in determining differing food plant reactions and hence hopper behaviour in habitats of differing vegetation. The type of vegetation through which a band marches to reach the spray line certainly affects feeding behaviour; the vegetation of a barrier reached after a march through terrain with little or no food will almost certainly be more voraciously attacked than one reached after a journey through constant, even if sparse, vegetation. This last type of ground has been aptly named " snack-bar vegetation " by C. Ashall of Desert Locust Survey and the implications are obvious.

We have by no means exhausted the possible implications of feeding on insecticidal action. Experiments by Pearson (1958) and MacCuaig and Watts (1960) have shown that feeding prior and subsequent to ingestion of insecticide affects the toxicity of stomach poisons. If hoppers of the Desert Locust are fed lethal doses of a stomach insecticide and then immediately afterwards allowed to feed on abundant fresh grass, resistance to the insecticide increases 1·5–2·8 times, in comparison with experiments where food was withheld after ingestion of the insecticide. Thus if swathe width is too small, even if a lethal dose is taken on the barrier, hoppers passing through and feeding on the clean grass beyond may well recover. In this connection account must also be taken of the problems likely to be presented by the phenomenal rate of growth of annual vegetation after rains in certain locust areas. Such effects have been suggested by MacCuaig and Ashall (unpublished results, 1959) after spray trials in Eritrea. The effect of fresh annual vegetation would be to dilute the concentration over the swathe width thus rendering the barrier less effective in itself, and also aggravating the problem referred to above of the effect of feeding on toxicity. It also seems possible that hoppers may in these circumstances be preferentially attracted to the new, fresh vegetation again with deleterious effects on kill.

Very little is known of the food plant preferences of locusts, although in general *Locusta* is, for example, a more strictly graminaceous feeder than *Schistocerca* which is rather catholic, at least in the laboratory. But food plant preference in mixed vegetation may be important, since field trials have shown (MacCuaig, 1960) that plant geometry greatly affects the pick up of spray particles. In trials in Eritrea with the exhaust sprayer, an average deposit of 75 mμ/g. over 50 yards was found on *Acacia*, whereas on grass the deposit was only 39 mμ/g. Another complication is the diurnal rhythm of feeding, present both in the Desert (Ellis & Ashall, 1957) and Red (Chapman, 1959) Locusts. Feeding is greatest during the morning and evening; consequently the toxicity of spray barriers may vary according to the time of day on which hoppers attempt to cross them; cumulative toxicity, however, may offset this possibility. But it is clear that in relation to the effects of feeding, work is required on the site, mode and speed of absorption of stomach insecticides in the mid-gut of locusts, and information on how this varies with type and rate of food intake, with locomotor activity and with temperature are all relevant to the efficiency of spray barriers.

A factor which helps to compensate for the variation in rate of food uptake is the reduction in rate of displacement of hopper bands when they move into vegetation and begin feeding. Figures given by Ellis and Ashall (1957) indicate that rate of movement may be reduced to half by vegetation, and Yule and Lloyd (1959) also observed a slowing up of Red Locust movement by vegetation. But the interplay of these factors needs investigation; if, for example, both marching and feeding are markedly temperature dependent, of which there are indications, reductions may occur in both simultaneously with a consequent offsetting of the value to control of reduced marching speed.

In considering the permissible distances between, and dispositions of, barriers to achieve minimum cost and maximum kill we must consider the mobility of the target and the persistence of the insecticide. With modern long-persistence insecticides the latter factor does not seem to be a serious limitation; concentrates of dieldrin for example have been observed to be still toxic to locusts as long as fifty days after spraying, although thirty days may be a safer average figure. But even this is satisfactory since it about covers the major portion of average length of hopper life (about twenty to thirty-five days in *Schistocerca*, thirty-five to forty in *Locusta* and fifty to sixty in *Nomadacris*) under reasonable environmental conditions. The problem of persistence is also related to a further extension of barrier spraying, in which barriers are placed through or near egg-fields, to kill the emergent hoppers (Pruthi & Bhatia, 1954; Milnes & Tompkins, 1954; Sayer, 1959). This is a method of great potential value, but much work is needed on the variation of incubation period with environmental conditions, the persistence of insecticide in various soils, and the formation and direction of movement of hopper bands after hatching.

The tactical problem therefore reduces to the setting of barriers in relation to the average rate and direction of displacement during life by hopper bands. Evidence from observations on the Red (Yule & Lloyd, 1959), Desert (Ellis & Ashall, 1957) and Brown (Smit, 1939) Locusts indicate the importance of gregariousness as a factor in both rate of movement and direction. In general, in these species, the larger the band, the faster the rate of movement and the lower the " wandering ratio," which is the distance moved divided by the resulting displacement in a straight line, which has a value of 1 for movement in a straight line. The distances covered by bands vary with such factors as the instar, density and nearness to moulting of the hoppers and vegetation and environmental conditions such as temperature and wind. The total effect of these factors is almost impossible to assess and the variations speak for themselves; thus a small band of the Desert Locust containing some 10–20,000 hoppers has been observed to move about two miles during hopper life, while a large band of four million moved twelve miles. In the Red Locust the maximum displacement during hopper life is probably something of the order of two to three miles (Yule & Lloyd, 1959). In trials held in the Rukwa to evaluate the maximum effective barrier spacing (Lloyd, 1959), the average derived from twelve trials was 963 yards, but because of the variations observed and the theoretical nature of some of the parameters in the estimate a figure of 500 yards was recommended. Subsequently trials at 250, 500 and 750 yards have been carried out (du Plessis, 1960) and at the two lower figures good control has been obtained. In the course of the work further observations on band behaviour were made and it was concluded that operations should not be carried out on hoppers much before one month after first hatching, because the relative distribution and immobility of young hoppers greatly reduced the efficiency of the control technique. Very few such controlled experiments have yet been possible with the Desert Locust, where greater mobility and area distribution aggravate the many problems discussed above. In some of the trials carried out, for example, in Libya in 1957 (Sayer, 1959) difficulties of interception were recurrent. It is also necessary to study the behaviour of bands in relation to their particular habitats in different countries; for example, according to the observations of Stower (personal communication) hoppers of the Desert Locust seen infesting the heliotrope mat vegetation of the Rajasthan desert area of India in summer moved far less and migrated less as bands than does the species in winter in similar vegetation on the Red Sea coast.

The influence of gregariousness is seen in relation to direction of movements of bands; both in the Desert Locust (Ellis & Ashall, 1957) and the Red Locust (Yule & Lloyd, 1959) and to a lesser extent in the Brown Locust (Smit, 1939) small bands and bands of less gregarious character tend to change direction both during the day and from day to day; large bands, on the other hand, often maintain the same general direction for several days at a time. In Eastern Africa, scientists of the Desert Locust Survey have noted a tendency for large bands to move in a certain direction in certain areas at definite times of the year. This problem of band displacement is clearly most important to the barrier spraying method; it is only partly susceptible to laboratory attack because the requirement of observing large numbers of hoppers moving over fairly long distance under controlled conditions cannot be met. But investigations can be made on the particular physiological mechanisms involved in such displacements. In studies at the Centre, we have, for example, been able to demonstrate a reaction of down-wind drift in locust hoppers, a pattern of behaviour apparently initiated but not controlled by changes in body temperature. This reaction can be reversed by olfactory attraction, but under laboratory restrictions we cannot be sure that in the field a large band, which has begun to move down-wind and which is then subjected to olfactory attraction to vegetation—a stimulus which by the nature of its origin will vary in space, time and intensity—will not still continue to move down-wind, because the gregarious inertia shown by the majority of locusts overcomes the initial reactions of portions of the band to the olfactory stimulus. The solution to the problem almost certainly lies then in comparative field observations of varieties of bands in a variety of habitats; but laboratory work on particular sensory phenomena, such as the reactions of individuals and small numbers of hoppers to light, radiation, wind speed, and other visual olfactory and acoustic stimuli, will facilitate the design and evaluation of the necessary field experiments.

The analytical approach to the barrier spraying method yields at present a somewhat confused picture; but the fact remains that the technique is capable of killing large numbers of locusts, despite our present ignorance of the exact course of events. Does this therefore mean that an empirical approach in the field would pay better dividends than a programme involving research on physiology and behaviour? Not so—for this reason. Control by concentrated persistent insecticides represents an advance over the use of poisoned baits almost as great as that of bait over trenching or beating or other primitive methods; until another method of correspondingly greater value is introduced the problem is to refine the present method as much as possible, to increase its efficiency and perhaps most important, enumerate those principles to be followed in adapting the method for a given species in a given habitat. This can only be achieved by research on the physiology, behaviour and ecology of the locusts.

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Operational Research

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Although (or because) " operational research " has become a fashionable phrase, it is perhaps useful to begin with a definition, for which one may suggest

" The application of the scientific method—or at least the arithmetical approach—to complex practical problems, and, particularly, to problems which have previously been considered intuitively, by the more empirical approach of ' the practical man '."

After which, one must immediately record one's firm conviction that in work such as field research in Africa it is inefficient not to make the fullest use of the empirical experience of the " practical man on the spot," in dealing with every aspect of the local environment—terrain and weather, vehicles and equipment, people and politics—and locusts. On the other hand, one has slowly come to realise that long experience in expressing opinions (for example, as to percentage kills, or even on swarm size) may be of limited value if the man expressing such opinions has never had any corresponding opportunity of verifying them. And, at a different level from that of the field research project, the direction of a locust control organisation repeatedly requires immediate administrative and financial decisions on points, particularly concerning control methods, equipment and materials (not to mention personnel), on which the technical evidence may be inadequate or, in the past, sometimes altogether lacking. Intuition accordingly has been—and still is—essential; but operational research now provides evidence which can often supplement, and occasionally replace, purely intuitive judgment. One suspects that this may illustrate a more general point, which may recur during the Conference's session on the link between research work and its application.

The operational research approach, as just defined, has been applied to the problems of locust control, over the years, in three successive stages—strategy, tactics and organisation. To begin with, the development of a rational overall strategy of control, based on Dr. Uvarov's original phase theory, first became possible following the discovery of the outbreak centres of the Migratory and Red Locusts, resulting from the field work of Lean, Harris, Brédo and others, together with the corresponding systematic mapping and biogeographical analysis of field data which have been outlined by Miss Waloff.

The second stage of application of the operational research approach has been to problems of tactics—the development of new control techniques; bringing to bear the resources of the laboratory on problems arising in the field; and the assessment of the performance and economics of the new technique relative to those of existing methods. This second stage is illustrated by recent developments of ground-spraying against nymphs (hoppers), and of aircraft-spraying against adult locusts.

The exhaust-sprayer, already mentioned by Dr. Haskell, was designed by H. J. Sayer (1959) on the basis both of experimental work and of his field experience during 1951 and 1952 with large spraying machines against Desert Locusts in Arabia and eastern Africa. This had led him to conclude that, owing to the mobility of such locust populations, ground-spraying machines must be numerous—and accordingly cheap—in order to maximise the number of occasions on which machines encounter locusts; and that the utilisation of individual machines must necessarily be intermittent and occasional, placing a further premium on simplicity, and, particularly, against providing any independent power unit for the sprayer. Hence the simple exhaust-sprayer, without moving parts, of which the prototypes were constructed, mainly from scrap (and successively modified), in a locust control workshop in Ethiopia. The principle is merely that of restricting the exhaust outlet of the vehicle, thereby causing both a mild back-pressure and the emergence of the exhaust gases at high velocity. The back-pressure, of a few pounds per square inch, is used to feed the insecticide from tank to nozzle; and the increased velocity of the exhaust gases—several hundred miles per hour—is used to atomise the spray, giving a drop-size (MMD) of about seventy microns, and a spray deposit averaging, in a light wind, about one quarter pint per acre over a swathe of about 100 yards. At an early stage in the development of the machine, R. J. V. Joyce, then Government Entomologist in the Sudan, directed attention to its potentialities for the direct application to vegetation of concentrated stomach insecticides (" vegetation-baiting "), in relation to the economics of bran-baiting (using about 0·1 per cent. of active ingredient), which was at that time the control-method most widely used against the Desert Locust, but in which the cost of transport of the bran could account for more than half of the overall cost of large-scale campaigns (the arithmetical approach).

Dr. Haskell has already outlined the range of problems of locust physiology and behaviour concerned in the exploitation of the further possibilities of " barrier spraying " offered by such a machine; and I should like briefly to enumerate the varied lines of research, both in the field and in the laboratory, which have already contributed to the development of the method.

It was shown, at first theoretically, that a spray as fine as this, applied over the low and sparse vegetation typical of many habitats of Desert Locust hoppers, would be deposited selectively on vertical plant surfaces rather than on the ground; a special spray-sampling technique was developed for testing this point in the field, and in due course demonstrated that this was in fact so in practice. Spray-formulations presented a series of problems: an essential contribution was made by Courshee, of the National Institute of Agricultural Engineering (working with the support of the Sudan Government), who showed (Courshee, 1959) that highly involatile solvents must be used—even dieseline was found to be too volatile for this purpose.

Quantitative laboratory determinations of the toxicity of dieldrin to Desert Locust hoppers, undertaken at the suggestion of the Anti-Locust Research Centre, provided figures, already quoted by Dr. Haskell, to show, in relation to the feeding-rates of the hoppers, the kind of deposit-density of insecticide that was needed. Special formulations containing twenty per cent. dieldrin in non-volatile solvents were devised; and, before any large-scale tests of the present machine were undertaken against locusts in the field, calculations had already shown an appropriate spray-deposit was likely to be produced. In view of the potential toxic hazards of the direct application of high concentrations of dieldrin, special field trials were carried out in the Northern Province of Kenya, with the co-operation of the Kenya Veterinary Department and of the Cooper Technical Bureau, to assess the possible risks of this technique to grazing stock, with reassuring results.

Finally, staff and facilities for the essential field tests against locusts have been provided, at various times, not only by the Desert Locust Survey in East Africa but also by the governments of the Sudan, Ethiopia and Libya, as well as by both Imperial Chemical Industries and Shell International Chemicals Ltd. The method was first used on an operational scale in Libya in 1957; it was not only quantitatively but conspicuously effective (Sayer and Rainey, 1958), and individual spray lines continued to kill hoppers and young adults which fed upon them up to four weeks after spraying, despite both driving sand and heavy rain. Since then, thanks in particular to the active and continuing interest of F.A.O., the technique has also come into use against the Desert Locust in Aden, Saudi Arabia, Ethiopia, Iran, Iraq, Kenya, Pakistan, Senegal, Somaliland and the Sudan. The machine, which is now in commercial production, had been earlier adopted for the control of grasshoppers in Australia and of flea-beetle in the Sudan, and may have other applications, particularly against pests of a low and sparse crop-cover.

Aircraft spraying against locust swarms was reviewed at the previous Commonwealth Entomological Conference, six years ago (Rainey, 1954). At that time, such operations were just emerging from the experimental stage; no locust control organisation was using aircraft as its main weapon of control; and, in the largest airspray campaign mounted up to that time, in Kenya and Tanganyika in early 1954, the application of some 162 tons of concentrated insecticide had been shown, by operational research, to have fallen far short of complete control of a major invasion of swarms. Since then, aircraft have become the principal weapon of a number of locust control organisations (both national and international); in Morocco, for example, following the introduction in 1955 of the aircraft spraying methods and materials developed in East Africa (Perret, 1956) some 6,500 tons of concentrated insecticide were applied from the air during 1955–59 (F.A.O., 1959)—and a further 3,000 tons by some twenty aircraft since October last.

Current practice and recent developments in the use of aircraft against the Desert Locust were comprehensively reviewed by an expert panel convened last year by F.A.O. (1959). The technical progress which has resulted from the application of the operational research approach to this subject—begun by Kennedy and Gunn during the early forties—is illustrated by a recent experimental operation near Hargeisa, in Somaliland, in which some 400 tons of flying locusts, equivalent to 600 acres of moderately dense swarm, were killed by half an aircraft load of a new insecticide in the course of a fourteen-minute flight (Rainey, 1958). Fig. 1 indicates some of the lines of research which have contributed to this progress.

Limitations of time have made it necessary to present the development of the exhaust-sprayer and of aircraft-spraying as " success stories," without reference to the unexpected

Fig. 1

OPERATIONAL RESEARCH ON AIRCRAFT SPRAYING OF LOCUST SWARMS:

A Summary of Progress

5 Nov. 1945				8 Sept. 1957
First quantitative field-trial (Gunn, Graham *et al.* 1945)	Laboratory research in *organic chemistry* and *insect toxicology* ↓	Laboratory research on *formulation & mammalian toxicology* ↓	Field research on *swarm-spraying* and *swarm-behaviour; theoretical analyses of spraying tactics* ↓	Recent quantitative field-trial (Rainey, 1958)
2,000 ×	improvement of 3 ×	increase of 34 ×	improvement of 3·2 →	660,000
locusts killed per litre of 2½% DNC applied by RAF Baltimore at an inclusive cost of OVER $300 PER TON OF LOCUSTS KILLED	times in *toxicity of insecticide*	times in *concentration of insecticide*	times in *efficiency of application*—in addition to exploitation of increased effectiveness of spray-material	locusts killed per litre of 85% diazinon applied by DLS Beaver at an inclusive cost of $5 PER TON OF LOCUSTS KILLED

turns these stories have sometimes taken (such as the discovery that densely settled swarms could, at times, provide better targets than thinly flying ones—perhaps more of a surprise to the writer (Rainey, 1956) than it should have been), or to the blind alleys which we have occasionally explored, such as the use of water emulsions through the exhaust-sprayer. Today there is only time to say that detailed studies of such setbacks have provided perhaps even more valuable contributions to the further development of the methods than have their successes.

So much by way of illustration of operational research on the strategy and tactics of locust control. The application of the operational research approach to the further problem of the overall organisation of control has been strikingly illustrated by the development of the International Red Locust Control Service (Gunn, 1960). The Service was originally established on the basis of field work, particularly of Allan, Harris and Michelmore, and was nursed by its first Director, Hans Brédo, through its rugged pioneering stage, when the new Service had necessarily to make such use as it could of such control methods and materials as were then available. In 1952 a scientific officer, J. H. Lloyd, was appointed to the Service, on the initiative of its then Director, Dr. Gunn, for the specific objective of developing more effective methods of control which would result in an overall reduction of costs. Thanks not only to the findings of Lloyd and his colleagues (Lloyd, 1959), but, above all, to the manner in which they were integrated into the overall policy of the Service, every control technique which had been in use against Red Locusts in 1952 was, within a few years, replaced by methods which had been shown to be more efficient ones; the effectiveness of the Service was vastly improved, so that, since 1954, without outside help, it has dealt, from the air, with upsurges of locusts on a scale previously beyond the scope of its own resources; and, finally, this enhanced protection against a Red Locust outbreak has been provided to the subscribing governments at an overall cost which has progressively decreased in each of the past four years.

Finally, back to the even more difficult proposition presented by the overall control of the Desert Locust. Miss Waloff has shown that the basis of strategy must be mobility of control units, to match that of the locusts; and, as far back as 1953–55, a pilot-scale air unit, operated by the Desert Locust Survey with the support of F.A.O., established contact with locusts in six different territories during twenty-six out of twenty-eight successive months, and sprayed during twenty-four of these months (F.A.O., 1959; Rainey, 1956). The exploitation of the full potentialities of the control methods and resources which are now available against the Desert Locust has thus become a problem, above all, of operational research on an international scale. It is therefore encouraging that in the new Desert Locust Project, begun this month by F.A.O. with the financial support of nineteen governments and of the United Nations Special Fund, operational research appears with appropriate prominence.

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Discussion

Mr. Q. A. Geering asked Dr. Rainey for an explanation of the way in which the aircraft spray runs were made in relation to the layout of the flying locust swarm. Dr. Rainey replied that the pilot of the plane selected a straight path across the top of the visually densest part of the swarm, and that this was done afresh for each run-in; as a swarm consisted of many groups of locusts, with the widest possible diversity of orientation between groups, each run-in, or spray-line, was effectively independent of those made before it, for the swarm could be regarded as re-randomising itself, while the plane was turning for the next run.

Dr. A. P. Arnason enquired whether crops had to be protected from spray-damage during such operations. Dr. Rainey said that this was not often a serious problem, since much of the control of swarms from the air was carried out in regions remote from cultivated areas. When spraying swarms over crops had been unavoidable, a minimum spraying height, usually 200 feet, had been specified from experimental data. There had, however, been one such occasion when large drops of DNC, due to temporarily defective jets on particular aircraft, had damaged sisal in Tanganyika; and the use of BHC had, on occasion, caused tainting on tea and on grass used for grazing.

Mr. T. Greaves asked, in view of Dr. Rainey's remarks that the swarm re-orientated itself after the passage of the plane, what immediate effect insecticides had on the locusts. The *immediate* effect was negligible, replied Dr. Rainey, even when DNC was employed, though with this insecticide half of the locusts killed by a particular operation could drop out of a travelling swarm within an hour of spraying. With less rapid materials, a corresponding stage would perhaps not be reached for twenty-four hours, and careful ground observations were needed to give accurate data on the effectiveness of such spraying.

Mr. L. P. Lefkovitch asked whether an opinion could be expressed on the effect on the total fauna of the use of dieldrin sprays over large areas, and whether any research was being carried out to elucidate such effects. Dr. Rainey said that no such work with dieldrin was known to him, but work on these lines had been carried out on such effects of the use of large quantities of BHC concentrates against swarms in Morocco, where the effects on the other insect fauna were said to be striking but not long-lasting.

DISCUSSION ON DEVELOPMENTS IN THE STUDY OF PLANT VIRUSES AND THEIR VECTORS, AND THEIR BEARING ON CONTROL MEASURES*

Chairman: Mr. F. C. Bawden, *Director, Rothamsted Experimental Station*

The Chairman opened the meeting by remarking that the transmission of fungal diseases by insects would have been an ideal subject for this first joint session of the Seventh Commonwealth Entomological Conference with the Sixth Commonwealth Mycological Conference, but unfortunately there were few people who could contribute to such a topic, and therefore viruses were the next best thing. Five years ago the title would have said " insect vectors," and recent advances to incriminate other animals were significant.

The Ways in which Plant Viruses are Transmitted by Vectors

By Dr. M. A. Watson
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Examples of plant viruses, grouped according to their vectors and the ways in which they are transmitted, are shown in the Table below, but it contains a lot of speculation, and will probably soon be out of date. The much abused terms, persistent and non-persistent, at least have definitive meaning but much of the rest is speculative, and I have had to make some enlightened guesses so as to include a reasonably representative collection of examples. However, the Table may serve some useful purpose if only as an aid to remembering the increasing variety of Invertebrate-transmitted viruses and their interactions with their vectors. This kind of information is not only necessary to those single-minded enthusiasts who worry about mechanisms of transmission but to all who are concerned with crop growth and food production, for the way in which a plant virus is transmitted determines how it spreads in crops and the kind of control measures that are effective against it. Also, grouping the viruses according to kinds of transmission emphasizes other similarities that help in diagnosis or investigation of new and unfamiliar diseases. Note the use of the expression " Invertebrate-transmitted." Up till recently we have been able to use " Arthropod-transmitted " as a collective adjective, but the discovery of nematodes as vectors of plant viruses compels the use of the more general term.

The three criteria I have used to distinguish the different kinds of transmission are: first the latent or incubation period, second the persistence of infectivity of the vectors, and third the passage of virus through the moult. The *incubation or latent* period is an interval between the acquisition of virus by a vector and the time when it is able to initiate infection in a healthy plant.

Persistence is the time for which a vector can go on infecting healthy plants after it leaves the infected ones. Viruses in Group I, for example, Henbane mosaic, hardly persist at all, hence the term non-persistent. Those of Group II, for example, Beet yellows, may persist for two or three days, Barley yellow dwarf, in Group IV, persists for two or three weeks, and striate mosaic for two or three months. Vectors of the last two sometimes do not infect the first plants they feed on, because of the delay period.

The third criterion, *passage of virus through the moult*, is based on whether or not an infective immature vector can go on causing infection after it has moulted and developed into a more mature form. All the vectors of plant viruses grow by sloughing off their exoskeleton when it becomes too small for them. The cast-off material or *exuvium* includes the chitinous skin and mouth parts and tissues derived from the embryonic ectoderm, the fore and hind gut, trachaeae and so on. All these are replaced each time before the old ones are discarded. Emergence from the egg is a special sort of ecdysis, so passage of a virus through the egg can be considered in the same category as that through the moult.

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* Joint meeting with the Sixth Commonwealth Mycological Conference

EXAMPLES OF VIRUSES GROUPED ACCORDING TO THE WAYS IN WHICH THEY ARE TRANSMITTED BY VECTORS

Groups	Vectors	Examples	Latent or Incubation period	Passage through moult	Persistence in feeding vectors
	Transport. External—Passive—Probably Carried on Exuviae				
Non-persistent I	Aphids	Henbane mosaic† Potato virus Y† Cucumber mosaic† Beet mosaic† Cabbage black ring spot† Cauliflower mosaic†	None	None	½ to 2 hrs.
Persistent II	Mealybugs	Swollen shoot	None or very short	None	From a few hours to 3 or 4 days
	Aphids	Beet yellows* Raspberry viruses* Strawberry mottle			
	Mites	Ryegrass mosaic†			
	Transport. Internal—Passive—Often Recoverable from the Blood				
III	Biting Insects	Squash mosaic† Turnip yellow mosaic†	None or short	Not known: not through metamorphosis	Days to months often depending on quantity of virus acquired by vectors
IV	Aphids	Barley yellow dwarf Carrot motley dwarf* Strawberry yellow edge Groundnut rosette	4–20 hrs.	Through the moult but not through eggs	
	White Flies (Aleurodidae)	*Bhendi* yellow vein Cotton leaf curl	6–8 hrs. 4–20 hrs.		
	Cicadellids	Beet curly top Maize streak	3–20 hrs. 12–30 hrs.		
V	Mites	Wheat streak mosaic†	Not known		
	Thrips	Tomato spotted wilt†	5–9 days		
	Nematodes	Grape fan-leaf† Arabis mosaic†	Not known		
	Transport. Internal—with Multiplication				
VIa	Aphids	Potato leaf roll	12–30 hrs.		
VIb	Cicadellids	Aster yellows Peach yellow leafroll	10–30 days		Usually months: not obviously dependent on quantity of virus acquired
VIIa	Cicadellids	Wound tumour Potato yellow dwarf† Green petal Clover witch's broom	10–30 days 4–8 weeks	Transmission through eggs infrequent	
VIIb	Cicadellids	Rice dwarf Clover club leaf	10–30 days	Transmission through eggs frequent	
	Delphacids	Rice stripe Wheat striate mosaic	7–30 days		

* Manually transmitted with some difficulty.
† Easily manually transmitted.

An example of Group I is henbane mosaic (HMV), a non-persistent virus affecting solanaceous plants used for drugs. It is transmitted by the Aphid, *Myzus persicae* (Sulz.). When tobacco plants are fed on by Aphids that have been starved and then fed for either two minutes or twenty-four hours on plants infected with HMV, those fed for twenty-four hours infect many fewer plants than those fed for two minutes (Watson and Roberts, 1939). This is an easily repeatable result so long as the feeding times given on the infected plants are really short. The optimum is between one and two minutes. When Aphids are left on the plants for even five minutes their infectivity is already lowered, and after one hour it is minimal.

Beet mosaic (BMV) is another non-persistent virus and it is interesting to compare its behaviour with that of beet yellows virus. Both are transmitted to sugar beet by *M. persicae*. BMV was best transmitted when the Aphids were starved and then given two minutes feeding on infected leaves. Unstarved Aphids were poor vectors after two minutes feeding, but did better after feeding a long time. However starving made no difference to transmission of beet yellows. Aphids that had fed for fewer than five or ten minutes on infected leaves did not transmit but they did so after longer times, and their efficiency increased with increasing feeding times up to about eight hours (Watson, 1946).

Non-persistent viruses, such as henbane mosaic and beet mosaic, are not only very rapidly acquired but also rapidly transmitted, the whole process taking only a few minutes, but they are lost within an hour when the Aphids feed on healthy plants. Beet yellows is slowly acquired and slowly transmitted, but Aphids may go on transmitting it for two or three days. When Aphids migrate into a sugar beet crop they often move about quickly at first and so transmit beet mosaic, but the virus must come from a nearby source, otherwise the vector would lose it on the way to the crop.

Beet yellows need not come from a nearby source, but its vector must feed for several hours on an infected plant to transmit it efficiently. When it is brought from a distance, infective Aphids are likely to be few and infect few plants, but these plants become foci of infection from which virus spreads while the Aphids are building up their summer infestation.

The actual mechanisms of transmission of these two kinds of viruses (Group I and Group II) are still very uncertain. The non-persistent viruses are so rapidly transmitted that they can do little else but adhere in some way to the mouthparts. Experiments have shown that they are probably carried on the extreme tips of the stylets (Bradley and Ganong, 1955). It has been suggested that they enter grooves, or get wedged behind scales or bristles on the chitinous surfaces of the stylets (van Hoof, 1958). If so, it is difficult to understand how different non-persistent viruses are specifically transmitted by different species of Aphids, and conversely, why very contagious viruses like tobacco mosaic and potato virus X are not transmitted in the same way. Even serologically related strains of non-persistent viruses may vary in their ability to be transmitted by different species of Aphids. Potato virus Y is readily transmissible by *M. persicae* but potato virus C is not, cucumber mosaic has many aphid vectors, including *M. persicae*, but its related strain from spinach is transmissible, apparently, only by *Aphis gossypii* Glov., and *Myzus ascalonicus* Doncaster (Badami, 1958).

Beet yellows mosaic is much less stable *in vitro* than beet mosaic, and yet it lasts much longer in the insect. Presumably it is carried on or in some tissue where it is protected from inactivation better than in plant sap.

As the Group II kind of viruses do not pass through the moult, they may be harboured in the insects on some part of the exuvium that is biologically active only between moults. At present there is no relevant information.

The viruses of Group III, transmitted by biting insects, are very stable *in vitro* and have had much interesting work done on them which does not concern us here. They may be transmitted by grasshoppers and possibly by Aphids, but their behaviour in these has not been studied. In beetles they survive for long periods in the alimentary canal and in the blood. They are probably injected into healthy plants by regurgitation. Freitag (1956) has said that Squash mosaic cannot survive pupation although both larvae and adults can acquire and transmit it. In the pupae of holometabolous insects nearly all the tissues break down and are re-organised. Probably the virus is destroyed by enzymes or discarded with the waste products. Perhaps that is why few plant viruses are transmitted by vectors with complete metamorphosis.

Barley yellow dwarf is an example of a Group IV virus. It has a short incubation period in its aphid vector, but long persistence. The cereal diseases caused by it are of great economic importance in many countries. Barley yellow dwarf is even more slowly acquired and transmitted than beet yellows virus. Perhaps ten per cent. of the Aphids can pick up some virus when fed on infected leaves for about two hours, but usually they will not transmit until they have fed on healthy plants for several hours more.

Aphids that feed on infected plants for a day are much more likely to infect than those fed for shorter times, and need less time on healthy plants. It is difficult to be critical about these times because they affect each other. The slowness of transmission may be because Aphids take a long time to acquire virus, or because they acquire so little that it takes a long time to reach the healthy plants, or because virus has been acquired but takes some time to pass from the alimentary canal to the salivary glands, which would in effect be the simplest kind of incubation period, and is usually accepted as such. All these factors would cause apparent delay between the Aphids having access to virus and being able to infect plants. As they are correlated it is impossible at present to measure their relative importance.

Other things could happen to the virus in the vectors as well as moving to the salivary glands, and one of these could be multiplication in the tissues of the vectors. We know that several hopper-transmitted viruses multiply in their vectors, and it has also been demonstrated that potato leaf roll virus does. But for this fact I would have included leaf roll virus in Group IV, because it is so like the others of that group. One is tempted to say that if leaf roll can multiply in its vectors so could yellow dwarf and carrot motley dwarf viruses also. However, if they do so it does not affect the efficiency with which they are transmitted. This is illustrated by the following results:—Aphids were fed on oats infected with yellow dwarf virus, and leaf hoppers on sugar beet infected with curly top virus, for one hour and for twenty-four hours. They were then removed to fresh healthy plants every day, until the Aphids had fed on twenty plants and the hoppers on 100 (Hoppers, of course, live much longer than Aphids). When fed for one hour on infected plants each Aphid infected " only one or two plants " out of the twenty fed on and the hoppers infected four, but when fed for twenty-four hours the Aphids infected fourteen plants and the hoppers infected twenty. The figures are taken from the work of Freitag (1936) and Rochow (1959). So the time of feeding on infected plants determined the amount of virus transmitted. This is true also of potato leaf roll virus (Heinze, 1959), although leaf roll is reported to multiply in its vectors (Stegwee and Ponsen, 1958). Multiplication would be expected to make transmission independent of the quantity of virus imbibed, as it does for wheat striate mosaic and some other leaf-hopper-transmitted viruses, but apparently it does not do so in Aphids. Perhaps the truth is that transmission of some plant viruses is only incidental to their behaviour in the vectors.

The next group is Group V. This contains a motley assemblage that probably have nothing to do with each other. Dr. Broadbent will mention spotted wilt virus, and Dr. Posnette will tell you about the nematode transmitted viruses, so I will quickly pass over them.

There is quite a wide variety of behaviour among the hopper-transmitted viruses in Groups VI and VII. Wheat striate mosaic provides examples of most, with some extra complications of its own. It is transmitted by *Delphacodes pellucida* F. and the symptoms it causes in wheat plants vary from fine broken chlorotic streaks to severe generalised chlorosis resembling that sometimes seen in genetic chimaeras. The plant-hoppers can pick up the virus from infected leaves in two or three hours and transmit in about half-an-hour, but they need at least a week to do both. Prolonging the times of feeding on infected and healthy plants increases the numbers of hoppers that acquire virus, but does not increase the infectivity of individual hoppers. Their efficiency depends very largely on their parentage, for different races vary enormously in their ability to acquire and transmit virus. Some are so poor that only occasional individuals will occasionally transmit; others are so efficient that almost all can become able to transmit constantly for months (Slykhuis and Watson, 1958).

D. pellucida exists in several races that vary in their ability to transmit wheat striate mosaic. When three groups of individuals from each of three races of hoppers were given equal opportunities to infect wheat seedlings, race A infected nine, race B twenty-nine and race C fifty-one plants. The incubation periods of the virus in the vectors also vary in the different races. Sixteen of race C, three of race B and none of race A infected within ten days of leaving the infected plants. In other words, race C infected much more quickly than the other races, because its incubation period was shorter.

Vectors of beet yellows, barley yellow dwarf and wheat striate mosaic lose infectivity at different rates when feeding on healthy plants. Beet yellows is optimally transmitted within a few hours, but is lost from the infective vectors within about seventy hours. Yellow dwarf starts to be transmitted at once provided the vectors have fed longer than a few hours on infected plants. The Aphids transmit highly efficiently for about a week, but then begin to fail with increasing frequency. Some completely lose the ability to infect. This suggests that their virus content is quantitatively limited.

Vectors of wheat striate mosaic virus do not transmit until at least a week after they acquire virus. Then the numbers of plants infected each day increase slowly, reflecting the different lengths of incubation periods by hoppers of varying vector-efficiency. Once a hopper becomes infective its efficiency depends mainly on its race and very little on its opportunity for acquiring virus.

Not only do the individuals of efficient races maintain a sufficient store of striate mosaic virus to infect plants for the rest of their lives, but they also hand it on to their offspring. And the offspring hand it on to their offspring, and so on, apparently *ad infinitum*, or at least for a great many generations. This behaviour has been used by Fukushi with rice dwarf virus and Black, for clover club leaf virus, to prove that plant viruses can multiply in the tissues of insects. Virus could be inherited through so many generations without renewal that there was no other possibility.

With striate mosaic not only are the young hoppers born infective, but the virus injures many of the embryos so that they fail to hatch. The embryos develop almost to the stage of emergence but then many of them collapse and die. Those that do emerge can usually infect plants as soon as they are hatched (Watson and Sinha, 1959). This means that really efficient races, if they acquire virus, are not able to breed as rapidly as less efficient or virus free individuals. Their progeny may be reduced to a half, or even to a quarter. So the better able they are to infect plants, the less likely they are to survive in nature. This is probably one reason why the virus does not spread rapidly in the field, even when the vectors are plentiful.

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Some Aspects of Virus Spread Among Plants by Vectors

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Most of the plant viruses that have been studied intensively infect crop plants of one kind or another, and when a plant species is cultivated as a crop the spread of a virus is much simpler and more rapid than among scattered individuals of a species in natural vegetation. Nevertheless many of these viruses are known to spread between wild plants as well as to crops, and it is not surprising therefore that most viruses have become associated with insects with considerable mobility, the Aphids and leafhoppers. Perhaps surprisingly a few viruses have acquired such sluggish vectors as mealybugs, mites and nematodes. One possible explanation is that these seemingly pedestrian animals (if one can call a nematode a pedestrian) are transported readily. For example, mealybugs are carried by ants, mites by Aphids and nematodes (in soil) on feet and implements. Indeed, man is an efficient vector of viruses, such as tobacco mosaic and potato virus X, that easily infect plants through broken leaf hair and small wounds made during handling. The propagation of virus-infected plants by grafting and rooting cuttings is the normal occupation of most nurserymen and gardeners!

Despite the recent discovery of several virus vectors in other groups of Arthropods, Aphids are still responsible for the spread of most viruses whose vectors are known. Aphids also display the widest diversity in methods of transmission. In the strawberry crop alone, different viruses persist in their aphid vector either for a few hours, a few days or for life, with no latent period, one of a few hours, or of about ten days respectively—mottle, yellow edge and crinkle viruses—(Prentice, 1952). Only the non-persistent viruses in Watson's sense have not been found in strawberry.

The period which Aphids retain virus influences spread, not only in the distance over which they are carried but also in the number of plants infected by migrating insects. Non-persistent viruses are transmitted in short feeding periods, of a few minutes, and many plants may be infected by a winged Aphid moving from plant to plant, and from field to field if there are infected plants from which the Aphid can acquire a fresh supply of virus. We find that once introduced, strawberry mottle virus spreads rapidly so that almost every plant in a field may become infected within four years (Posnette and Bovey, 1952). The viruses that persist for days in the strawberry Aphid are not often transmitted in feeding periods less than an hour and several hours are necessary to ensure infection. These viruses therefore spread more slowly than those which are less persistent and there is good evidence that yellow edge, for instance, is spread within the crop mainly by crawling apterae. Because it persists in the Aphid, however, it is carried long distances by alate Aphids and in the first season of an isolated field planted with virus-free plants, more yellow edge than mottle virus is usually introduced. Much of this spread into the crop occurs in the autumn, during the second migration of the strawberry Aphid, when the insects move less frequently from plant to plant and presumably feed for longer periods on each than in the summer. The peak period for the spread of the short-persistent mottle virus is during the main migration of alatae in June, in weather more favourable for frequent flights and hence for short feeding periods on each plant (Posnette and Cropley, 1954).

Whereas strawberry viruses differ greatly in their relationships with their Aphid vectors, the viruses that are restricted to raspberries all behave like strawberry mottle virus, and persist for hours rather than days in the Aphid vectors, *Amphorophora rubi* (Kalt.). The gooseberry vein-banding virus is also of the short persistence type, and, like the strawberry mottle virus, can be transmitted by several different genera of Aphids (Posnette, 1952). In this respect the viruses of short persistence resemble the true non-persistent viruses rather than those of long persistence; the latter are usually transmitted only by related species of Aphids in which they have a latent period.

A long latent period between the acquisition of the virus by the vector and its becoming able to infect a plant is characteristic of hopper-transmitted viruses. There is good evidence that some of these multiply in the insect and three seem to affect their vector—aster yellows (Littau and Maramorosch, 1956), wheat striate mosaic (Watson and Sinha, 1959) and peach yellow leaf roll (Jensen, 1959). Probably all viruses that have latent periods measured in weeks and pass through the egg of the hopper do multiply in the vector, although unequivocal evidence is available for only five—the viruses causing rice dwarf transmitted by *Nephotettix apicalis* (Motsch.) (Fukushi, 1940), clover wound tumour by *Agallia contricta* Van D. (Black and Brakke, 1952), clover club leaf by *Agalliopsis novella* (Say.), (Black, 1950), aster yellows by *Macrosteles fascifrons* (Stål), (Maramorosch, 1952) and corn stunt by *Dalbulus maidis* (De Long and Wolc.), (Maramorosch, 1955). Strawberry green petal and the clover witches broom viruses may be similar as they have long latent periods of four to eight weeks in the vector and are transmitted through the egg (Frazier and Posnette, 1957; Posnette and Ellenberger, unpublished).

It can be argued that such viruses ensure their survival in two ways. If their plant hosts should die, the viruses can survive in the vectors, overwintering or aestivating in their eggs; if their insect hosts die, the viruses can survive in perennial plants like clover. Perhaps this is one reason why hopper-transmitted viruses are more damaging to crops than those spread by Aphids in the semi-desert regions of North America, Australia and Southern U.S.S.R. However, rice is hardly a semi-desert crop and indigenous aphid-transmitted viruses certainly occur not only in Britain but also in dry regions like California causing such diseases as red leaf of Filaree (Frazier, 1951).

In the tropical rain forest zone of West Africa most indigenous plants continue growth during the dry season and no hopper-transmitted viruses have been recorded (with the possible exception of maize streak). Aphids spread the tristeza virus causing lime dieback (Hughes and Lister, 1953) and groundnut rosette. White flies, *Bemisia gossypiperda* Misra and Lamba, spread the viruses that cause tobacco leaf curl, cotton leaf curl and cassava mosaic. Undoubtedly there are many viruses infecting indigenous plants awaiting investigation. Cacao is not indigenous to West Africa and there is little doubt that the three viruses causing diseases in this crop have spread from wild hosts. Moreover, the diversity of strains of the swollen shoot virus suggests that it had a long history in indigenous plants before it attracted attention by its spread to cacao. The swollen shoot virus has been found in trees of *Cola chlamydantha* in forest reserves some miles from the nearest cacao farms (Todd, 1951), and the mottle leaf virus in baobab trees (*Adansonia digitata*) also in areas where it is unlikely that they became infected from cacao (Attafuah and Tinsley, 1958). These two viruses are spread by mealybugs, *Pseudococcus* spp. (Posnette, 1950) but no vector has yet been found for a third virus, cacao necrosis (Thresh, 1958).

Cacao swollen shoot virus persists for at least two days in mealybugs that are not feeding and some dispersal probably occurs by wind-borne larvae. Some spread over short distance is probably effected by ants (*Crematogaster* spp.) carrying mealybugs to fresh feeding sites (Cornwall, 1958). Certain species of ants play a major part in the ecology of the main vector species *Pseudococcus njalensis*, Laing, covering them with protective tents of vegetable debris and soil. They also enable them to colonise the hollow stems of *Canthium glabriflorum* trees (Strickland, 1951) which support massive mealybug populations although they are not hosts of the virus. Spraying with dieldrin to eliminate ants has a drastic effect on the mealybug population and reduces the rate of virus spread.

In natural forest, dispersal of virus may be assisted by fruit bats that are attracted to the seed of *Cola chlamydantha*. The fruit pods split open while still attached to the tree, and mealybugs then enter; they have been found feeding on the seeds, some of which became infected with virus. Infected seed is dispersed by fruit bats and *Cola chlamydantha* seedlings, including some which are infected, frequently occur beneath the giant kapok trees used as bat roosts. Although seeds of several species, including cacao, are readily virus-infected by mealybugs, no true seed transmission of these viruses has been demonstrated (Posnette, 1947).

Turning from insects to mites, for many years the only plant virus known to be spread by Arachnids was that causing reversion of blackcurrants, transmitted by *Cecidophyes ribis* (Westw.) the mite which causes symptoms of big bud (Massee, 1952). A disease of cotton was reported to be transmitted by *Tetranychus telarius* L., but this seems equivocal as the author also claimed transmission by several aphid species (Moskovetz, 1940). Now it is known that fig mosaic virus is carried by *Aceria ficus* (Cotte) (Flock and Wallace, 1955), wheat streak by *Aceria tulipae* (Keifer) (Slykhuis, 1955) and peach mosaic by *Eriophyes insidiosus* Keifer and Wilson (Wilson *et al.*, 1955). What little is known about the transmission process suggests that the viruses persist for at least several days in the mites, and

Slykhuis suggested that the wheat streak virus is acquired by the nymphs but not by the adults.

The information recently acquired on virus transmission by nematodes suggests that the viruses persist in the vector for some weeks. Raski and Hewitt (1959) found that dagger nematodes (*Xiphinema index*) could transmit the fanleaf virus of grape vine after thirty days without a host plant. We have shown that nematodes of a related species, *X. diversicaudatum*, retain Arabis mosaic virus not only during fasting periods up to thirty-five days but also through 15-day periods with a host plant (Jha and Posnette, 1959 and unpublished). It is not possible to prove that the nematodes fed on plants that did not become infected, and therefore evidence in favour of a latent period is equivocal. Whatever the correct interpretation, nematodes used in several experiments have infected a second series of test plants after periods up to fifteen days in contact with plants that they did not infect in the first series. One example is shown below.

Persistence of Arabis mosaic virus in nematodes (*Xiphinema diversicaudatum*)

First test feed		Second test feed
Duration in days	Plants infected	6 weeks duration Plants infected
5	4	10
10	6	9
20	7	9

25 nematodes per pot; 10 petunia plants per treatment

Diseases caused by " soil-borne " viruses which have been shown or are thought to be nematode-transmitted recur on the same sites for many years, usually spreading very slowly by comparison with insect transmitted viruses. This suggests that the viruses may persist in the vectors. However, most soil-borne viruses have wide host-ranges and could survive fallow periods or rotations of immune crops by infecting weeds. Some are known to be seed transmitted and can thus be dispersed and also survive in conditions temporarily unfavourable for their host plants (Lister, 1960). Nevertheless it seems improbable that nematode-transmitted virus diseases would be troublesome in crops unless the vectors were able to retain the virus for long periods.

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The Behavioural Fitness of Aphids as Field Vectors of Viruses

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Among all that varied assemblage of vectors on Dr. Marion Watson's up-to-date list, the Aphids still stand out as much the most numerous. Over 180 species of *Aphidoidea* have been convicted of virus transmission in the laboratory. Between them they are known to transmit some 160 viruses. Of these, the majority are viruses of the non-persistent type which make up the largest single class of known plant viruses, and transmitting them is apparently an aphid monopoly. Spreading virus disease through the flora seems to be a major commitment of these insects—almost a part of the aphid way of life. It would be interesting both scientifically and practically to know why.

As far as habits are concerned, some of the answer has recently been emerging. Aphids now appear to be so ideally fitted, behaviourally, for virus spreading in the field that one is prompted to ask, not why they are so successful as vectors, but why they are not more successful: why they do not prevent us from raising any healthy crops at all.

There is one way, it is true, in which recent work shows Aphids to have less opportunity for virus spreading than we thought. It turns out that the whole period when virus can be carried on the wing is but a brief, early interlude in the life of the individual winged Aphid. Its flight muscles break down in a few days, if it manages to live for so long; and most individuals do not. Dr. Johnson and his colleagues at Rothamsted have provided strong circumstantial evidence from the plotting of hourly trap catches day after day, that the great majority of migrants perish after a flying life totalling at most a few hours. So the individual winged Aphid has not much time for virus transmission in nature. But against this must be set the huge numbers of winged Aphids produced, and also the second main point that has emerged from recent work, namely, that dispersal takes precedence over host finding in the behaviour of aphid migrants. Although the only survivors are those that find and settle down on a host plant, nevertheless the migrants are not attracted toward their specific hosts, nor do they settle down at all readily when they do come upon one.

It was natural perhaps to expect that Aphids like other insects would be able to identify, and direct themselves toward, their own host plants, by smell. But no evidence of this has been forthcoming and field observations on several Aphididae show that they alight indiscriminately on hosts and non-hosts of comparable appearance. Host selection occurs only after alightment, by means of still quite unknown stimuli received from the outside or inside of the plant when the Aphid is actually sitting on it and probing.

Apart from optomotor responses which need not concern us here, the only known directed reaction in these insects when they are air-borne is to light, a simple phototaxis. Fresh Aphids, taking off for the first time in a state of intense locomotory excitability, are most strongly attracted to the short-wave end of the spectrum including ultra-violet. This form of the phototaxis takes them up into the open sky where they are carried and so dispersed by the circulating atmosphere. The phototaxis then changes its form. In due course the fliers become relatively more attracted by the long-wave end of their visible spectrum: green, orange and especially yellow. These are the wave-lengths that predominate in light reflected from the ground, in contrast with the sky, and this change in the phototaxis seems to be what brings on the low-level, non-migratory kind of flight that we often observe, when the flora is sampled in a succession of alightments.

Not all species have a special preference for yellow, and those that do have one are certainly not helped by it in finding their specific host plants, considered as botanical taxa. For example, the Cabbage Aphid has been recorded landing on sugar beet in preference to cabbage, beet leaves being yellower than cabbage. The yellow preference seems rather to bias alightments toward plants that are physiologically suitable for colonisation. An interesting, special case of this is the attraction of *Myzus persicae* (Sulz.) by the colour of sugar-beet plants suffering from virus yellows disease, for on these plants the Aphids also multiply faster than they do on healthy beets.

The second mechanism by which dispersal takes precedence over host finding is more important. This is the development in fresh winged adults of a temporary inhibition of the feeding and larviposition responses normally elicited by contact with a host plant. At this stage the Aphids will not settle down even on the best of host plants. This inhibition is in fact the prerequisite for flight and hence for dispersal, and flight activity is in turn what progressively removes it. Once removed by a long flight the inhibition is however, easily re-imposed by contacts with unsuitable plants—contacts that are frequent in the field because alightments are so indiscriminate. The inhibition of settling, and the accompanying locomotor excitation, are in consequence astonishingly persistent in the field. The overwhelming majority of alighters, on non-hosts and on their own hosts alike, take off again within minutes. They stay longer on the average on hosts than on non-hosts and a small minority stay long enough to larviposit on a host, especially when they are caught and held there by the onset of darkness or other conditions that depress flight. But a large fraction of these stayers, too, leave again some hours later.

The key point for virus transmission is that fliers become ready to respond to the sight of plants by alighting well before they become ready to stay there for good. For virtually every alightment is promptly followed by at least one probe before the Aphid takes off again.

Only a handful of species have been watched closely so far, but the inference is that repeated and often indiscriminate alighting and probing on plants is typical of migrant Aphididae. We need much more information on the behaviour of other virus vectors before we can compare their behavioural fitness for virus spreading, with that of the Aphids. But it is at any rate rather difficult to imagine a behaviour pattern that would be more conducive to virus spreading in the field, than that of Aphids. That applies to persistent and non-persistent viruses alike. It is hardly surprising that there are several cases on record where the spread of non-persistent virus in a crop is done mainly by Aphids not colonising that crop. K. G. Swenson, when reporting this situation with bean yellow mosaic virus in gladioli, understandably demurred from K. Heinze's proposal to call non-colonising vectors " occasional " vectors.

Nevertheless there are evidently limits set to the virus-spreading activity of Aphids, and some of them seem to be behavioural. For example, quite a number of aphid species have been proved able to transmit the cabbage black ring spot and cauliflower mosaic viruses in the laboratory. But these viruses seem to spread in English brassica crops only when the two vectors that colonise brassicas are flying: *Myzus persicae* and *Brevicoryne brassicae* (L.). That is just the kind of limitation on vector activity to be expected from the purely behavioural evidence: a definite bias in favour of the host plants of the vectors.

Such a bias seems inevitable with the persistent viruses, owing to the long feeding periods required for their transmission. The common plant host makes a firm bond here between virus and vector that is lacking with non-persistent viruses. Perhaps this is one reason for the higher degree of vector specificity found with persistent viruses.

Non-persistent viruses require only brief probes for transmission, and such probes are by no means confined to the vector's own host plants as we have seen. But even with non-persistent viruses, a bias toward the vectors' own hosts during virus spreading presumably exists in the field, because the probes made by alighters on non-hosts are fewer and much more often too brief, than the probes made on hosts. In addition, the very property of non-persistence of these viruses in the vector tends to confine transmission to short flights*; and for ecological reasons short flights are more frequent between hosts than between non-hosts.

The ecological reasons are these. Aphid migrants travelling for some distance in good flight conditions and then alighting on plants, tend to accumulate on their hosts, but not on non-hosts, because they dally longer on their hosts before leaving again. When they become ready to take off again from the hosts they are more likely to find conditions have changed, and now prevent or restrict flying, than are the Aphids that have landed on non-hosts and take off again promptly. Hence many more Aphids take off from hosts in conditions permitting only short flights. Since plants tend naturally, or are forced, to grow together in stands of one kind, short, virus-transmitting flights are more likely than long flights to be between plants of the same kind: host plants in this case. Longer flights are less likely to lead to another host and are at the same time less likely to be virus-transmitting flights. For the same ecological reasons, it should be noted, there are more alightments on hosts than on non-hosts in spite of the fact that the individual alightments are indiscriminate.

In those three ways the spread of non-persistent viruses will tend to be concentrated among the host plants of the vector. But this needs a qualification. Probing *too* long on a plant reduces an Aphid's chances of picking up a non-persistent virus from it, while settling down on a plant of course precludes any transmission. For these reasons spread among most-favoured and highly specific hosts of the Aphids seems less likely than spread among only moderately good or " borderline " hosts.

The other and perhaps the principal limitation on the Aphids' potential for universal spreading of non-persistent viruses is what is called " vector specificity ": the intrinsic variation between Aphids in their ability to transmit and between viruses in their transmissibility by Aphids. By " intrinsic " is meant any variation not attributable to visible behavioural differences as for example in readiness to probe on given plants. Unfortunately much of our information on vector relations comes from tests in which the intrinsic factors were not distinguished, experimentally, from the behavioural ones. Not everybody has the patience or time to use a hand lens and stopwatch to make sure that the test Aphids probe equally long on the plants. This is unfortunate, because it is the diverse combinations of the separate intrinsic and behavioural factors that make up the whole cloth of virus ecology with which we are concerned in practice.

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* Strictly speaking, the non-persistence of the virus in the Aphid tends to confine transmission, not directly to short flights, but to the first few plants visited by short or long flights, after the virus has once been picked up. But most plant visiting occurs when flights are short, inevitably. Only near-by plants can then be infected, for the Aphid will have lost its infectivity before it reaches more distant ones. It should be stressed that there is no evidence of loss of infectivity on the wing, when no probing is done. The virus property of non-persistence does not, therefore, make long *uninterrupted* flights less likely than short ones to be virus-transmitting flights (contrary to what might be inferred from the next paragraph in the text). Non-persistence does, however, make transmission over a long distance less likely than over a short one, because the Aphid is likely to have visited more plants in the course of flying the longer distance. There is also an ecological reason quite independent of virus non-persistence (and stated in the text) why short flights are more likely to spread virus than long flights, even when uninterrupted. It is that near-by plants are more likely to be susceptible plants like the one from which the virus was picked up, than are distant plants. Non-persistence may reinforce this effect when loss of infectivity through probing distant, non-susceptible plants prevents transmission to any susceptible plants visited later.

It now appears that the transmission even of non-persistent viruses, at the very tip of the stylets, as R. H. E. Bradley elegantly showed, is nevertheless not just mechanical and accidental, after all. In other words, Aphids are not obliged to transmit viruses that are present in the plants when they probe. And yet they do transmit some of them. In the field their behaviour is such that they could well transmit more. Yet they do not, again for some intrinsic reason. The mechanism of this vector specificity is a hotly-pursued quarry of research which will no doubt be tracked down before long. But we need also for practical purposes to consider what in the field governs the incidence of aphid ability to transmit, and of virus transmissibility, whatever the mechanism. To put it another way, what is the significance of vector activity in the biology of the three partners: insect, virus and plant? It is scarcely credible that virus transmission is nothing but a by-product of the aphid way of life, devoid of any significance in the Aphids' biology, when they do so much of it, and when the result of it is radical changes in the physiology of the plants upon which the Aphids as parasites so closely depend.

Given the Aphids' behavioural bias in favour of their own host plants when spreading virus in the field, it would obviously " pay " the viruses (evolutionarily speaking) to be transmissible by those Aphids that parasitize the same plants as the viruses. Vice versa, it may often " pay " Aphids to transmit viruses that parasitize their host plants, since we know that in some cases the virus disease in the plants favours the Aphids' multiplication. Thus the extent to which Aphids and viruses share the same host plants could be one factor governing the incidence of vector specificity. Certainly this is not the whole story, for it is by no means the rule for viruses and their potential aphid vectors to share the same plant hosts. That was made abundantly clear in the case of onion yellow dwarf virus and has been repeatedly confirmed in other cases, notably by K. Heinze. It has still to be proved that there is even a tendency to such host-sharing by the non-persistent viruses and their specific vectors as determined by laboratory tests.

Dr. M. F. Day in Canberra, Dr. V. F. Eastop at the British Museum and I have been surveying the literature to see if there is any usable evidence on these points. Putting all the records together, it already seems that the notoriety as vectors possessed by the familiar polyphagous species, such as *Aphis gossypii* Glover, *Macrosiphum euphorbiae* (Thos.) and *Myzus persicae* (Sulz.), cannot be due solely to their having been tested on more viruses than the oligophagous species, although that is often taken to be a sufficient explanation. It is true that they are the favourite species for use in transmission tests. But there are far more oligophagous species (defining oligophagy as having host plants in not more than twenty families) so that the total tests that have been made on them (approaching 500) exceed the total tests made on polyphagous species (around 300). If now we compare the percentages of successes and failures of experimental transmission by Aphids of the two types, we find that the oligophagous ones have failed distinctly more often. Whether this is an artefact, due to more specimens of polyphagous Aphids being customarily available and used, thus simply inflating their chances of success; or whether the explanation is behavioural, the polyphagous Aphids perhaps probing more because the test plant is more often an acceptable (but " moderate ") host for them; or whether the polyphagous Aphids are better vectors for some more intrinsic reason—we do not yet know, and may not be able to find out from the literature. One has a fair jungle of variables to contend with when four biological entities are involved: virus, plant, insect and experimenter.

But these are at any rate some of the questions that call for answers in the present state of our knowledge of aphid-virus ecology, and that is still little knowledge indeed.

Control by Insecticides of the Spread of Plant Viruses

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Most virus diseases of economic importance are spread by insects, so insecticides might be expected to prevent or decrease virus spread by eliminating the vectors. Unfortunately many still remain uncontrollable by this method for reasons outlined below. Insecticidal control must aim at eliminating the vectors, or preventing their movement, or both, and is very much harder than preventing damage by insects as " pests," which is usually achieved by decreasing their numbers to a low level.

To prevent the spread of non-persistent viruses, an insecticide would have to kill incoming winged insects very quickly, whereas a slower-acting insecticide could be expected to prevent the spread of persistent viruses, particularly from plant to plant within a crop. Early experiments on insecticidal control of virus spread usually failed because the insecticides then available did no more than kill the insects already infesting the crop. Success has depended on the development of persistent insecticides, either contact or systemic, that can be applied before insects infest the crop, and kill them when they do.

Some of the most intensive work with contact persistent insecticides was done in the U.S.A. to control the spread of beet curly top virus to many types of crops by leafhoppers. In addition to spraying the food crops, leafhoppers were attacked on their winter hosts in the desert, which were often hosts of the virus as well. Except for planting resistant varieties, this indirect method of attack was the only satisfactory way of controlling curly top. Similarly spraying the weed borders of lettuce fields with parathion or DDT was more effective than spraying the crop in preventing infective leafhoppers from spreading aster yellows virus. With carrots, too, it has not proved possible to prevent incoming leafhoppers from introducing aster yellows virus, though subsequent spread within the crop could be prevented.

Spotted wilt virus is of the persistent type, as are the leafhopper-transmitted viruses, but like those just mentioned, it is from weeds that the thrips vectors mainly acquire the virus, and insecticides have so far failed to prevent its introduction into cultivated crops.

Much of the work on insecticidal control has been done on potato and sugar beet crops and here again it has proved impossible to prevent infective Aphids from introducing viruses, either persistent or non-persistent ones. Prevention of virus spread from sources within the crop has been achieved, however, particularly with the persistent viruses, potato leaf roll and sugar beet yellows, thus enabling potato stocks to be kept longer and delaying the spread of beet yellows till later in the season, with consequently less loss of sugar.

Contact insecticides such as DDT emulsion have proved as efficient as systemic ones in England on potatoes, although systemic insecticides should, in theory, be better because they penetrate into new growth which would not be covered by a contact one. Also systemic insecticides may be more selective than contact ones and not harm the predators and parasites of Aphids, which might prevent an aphid infestation from developing after spraying ceased. Control of leaf roll virus has been possible in areas where spread is mainly within a crop, and even in areas where it was often introduced, but then only when most growers undertook a spraying programme, as in the states of Maine and Washington. Co-operation in a spraying programme by growers has also stopped the spread of strawberry yellows within and between crops in Washington, U.S.A., where formerly the virus severely limited strawberry production.

In English potato crops both leaf roll and the non-persistent virus Y are spread mainly in early summer by winged Aphids which pick up virus from sources within the crop. The unexpected success in decreasing the spread of virus Y by about half that in unsprayed plots was due to the Aphids being killed before they made so many flights as they might otherwise have done.

DDT has not proved so successful on sugar beet as on potatoes, and control of yellows virus is now largely by systemic insecticides such as demeton, demeton-methyl and schradan. Such control is never absolute but is of great economic benefit, for sometimes one spraying at the appropriate time in late June may more than halve the proportion of plants with yellows at the end of the season. The virus not only affects the root crops but causes seed plants to yield poorly and these also act as sources of virus for the root crop. Preventing the spread of yellows virus within seed crops has almost doubled the seed yield, but spraying alone in non-isolated areas did not always give sufficient control because it did not stop Aphids bringing virus from the root crops.

Most persistent insecticides remain active on or in the plant for only two to four weeks when applied as sprays, and frequent sprayings are necessary if the plants are to remain toxic to insects throughout the season. Fortunately it is seldom necessary to ensure this; many plants become more resistant to viruses as they age, or source plants are more effective at one time than another, and insects are not always equally prevalent or active. For optimum effect with minimum effort the epidemiology of the disease to be controlled must be studied and insecticidal action be integrated with cultural control methods. For instance, the removal of infected potato plants to maintain the health of stocks was often useless because Aphids spread virus before diseased plants could be recognised. Now spraying will prevent the spread of leaf roll virus from such plants and spraying can stop when they have been removed if virus Y is absent.

Many experiments are now being done with systemic insecticides applied to the soil or tubers before or at planting. If they will make the plants toxic to insects throughout the season (and some do that) but the plant product is not toxic to mammals, effective control of spread of persistent viruses, and partial control of non-persistent ones, may be achieved without the labour of frequent spraying. Such application of insecticides certainly has a future in protecting seed crops and ornamentals.

Discussion

The CHAIRMAN said that the degree of vector specificity required investigation, especially with viruses that were apparently transmitted mechanically. Transmission by an insect was probably as variable a factor as any other, and indeed there were cases of a virus having two strains which could only be distinguished by the identity of the insect that transmitted them. Some insects could suddenly cease to function as vectors, and the reverse was equally possible, but such aspects had not been mentioned by the speakers.

MR. A. R. MELVILLE asked whether, just as an insect could cease to act as a vector, a plant—especially a perennial—could cease to be infected after inoculation. The CHAIRMAN replied that there were a few records of recovery, especially when the plants had been kept at a high temperature, and many records of the virus content of a plant decreasing, but such loss was not comparable to the rapid loss in the case of an insect. DR. WATSON confirmed that beet that had recovered from an attack by the yellows virus could subsequently be re-infected.

DR. B. L. CHONA reported that, in India, a certain amount of recovery had been observed in sugar-cane grown from cuttings from canes infected with mosaic. The extent of the recovery depended upon the strain of the mosaic virus. The CHAIRMAN warned that this was probably not the same kind of recovery; viruses were not totally systemic, as was once thought, but infected certain plant parts more than others. Sectioned potato tubers could be variably infected, and doubtless the same was true of sugar-cane setts.

In reply to a question from the Chairman, DR. POSNETTE said that there were indeed many vectors still to be discovered, although Aphids were still those most frequently encountered, and it was probable that new vectors would be found to occur in animal groups not yet considered as virus vectors. The transmission of some viruses was complex, and he cited that of peach necrotic ring spot, which was transmitted by none of the insects associated with *Prunus* and would only spread from tree to tree when the fruit had ripened, so that some factor associated with pollination had been considered to be involved. DR. L. BROADBENT wondered whether it could be mechanically transmitted by some such factor as birds eating the fruit, but DR. POSNETTE thought such a method unlikely because the condition had proved very difficult to transmit mechanically.

DR. C. G. JOHNSON suggested that the transmission of a non-persistent virus of strawberries in the autumn was associated with the flying habits of the vector: in summer, the majority of the Aphids flew at a height of about 100 ft., whereas in the autumn seventy per cent. of them were low-flying. It would therefore be expected that a non-persistent virus would be more transmitted in the autumn than in summer, and by analogy strawberry crops would be ill-sited in river valleys.

DR. C. J. MAGEE thought that the demonstration of the transmission of viruses by nematodes was the most interesting development since the previous Conference, and he asked whether there was any information on current views in the U.S.A. on the possible vector of the first recorded soil-borne virus disease. DR. POSNETTE replied that he and the Chairman had recently heard it said that such viruses were not transmitted by nematodes, although probably other vectors in the soil were able to do so. In any case, such viruses could persist for six years in dried soil.

The CHAIRMAN enquired whereabouts in the body of the insect virus multiplication took place. DR. WATSON said that Aster Yellows virus had been found by Maramorosch in altered cells of the fat-body, where they apparently caused the insect no harm. Streak mosaic multiplied in the egg, which died when an injurious level of virus had been reached. She felt that there was a possibility that multiplication could occur in the mycetome, where some appearance of fuzziness was visible microscopically.

The CHAIRMAN said that Dr. Broadbent's remark that early experiments with insecticides had failed was an understatement—they had increased the spread of viruses. During the war, experiments at Rothamsted with nicotine had killed ninety-eight per cent. of the Aphids on a crop, but the remaining two per cent. were dispersed by the application and caused damage over a much wider area. A similar state of affairs occurred in the U.S.A., where potato pests were controlled in plot trials by the use of DDT, but the Aphids remaining then moved from the plots and caused virus diseases to appear elsewhere. The introduction of persistent insecticides changed the picture. In the U.S.A., success was usually achieved by collaboration between the growers in an area, for they had speedily recognised that they all had to spray for mutual protection. In the United Kingdom we had fewer Aphids, and the effects on sugar-beet were not the same as those on potato. With the latter, it was the following year's crop that had, in effect, to be protected, while with sugar-beet it was the current crop, under which circumstances 100 per cent. infection of beet was not the great worry that some might think it. He agreed with Dr. Kennedy that it was surprising that we had any healthy plants, but it was a fact that sugar-beet paid for spraying even when ninety-seven per cent. was infected, and that was substantiated by the £5 million netted by the growers in 1959 after spraying costs had been subtracted.

DR. K. MELLANBY wondered whether, in view of the fact that insecticides are slow to kill Aphids, the drop in transmission rate was perhaps caused by a change in the vector's behaviour, such as the inhibition of feeding induced by a sublethal dose or a repellent action. DR. BROADBENT was able to say that Aphids were not usually put off their food by the use of insecticides, and that in any case much of the result would depend upon whether one was dealing with a persistent or non-persistent virus. With a non-persistent form, immediate kill was essential for control, but longer-term results might be improved. It was difficult to generalise, for the number of factors in operation was large and included the type of toxicant in use and the age of the Aphid population. Chemists had been asked to find an agent capable of rapid paralysis, for such a material would be invaluable in preventing the spread of viruses.

DR. G. D. HEATHCOTE confirmed that Aphids continued to probe although suffering from the effects of an insecticide, and said that they often died with the proboscis still inserted in the plant.

The CHAIRMAN having asked for comments from areas where vectors other than Aphids were important, DR. B. L. CHONA reported that delaying the infection of tomatoes by tomato leaf curl virus in India resulted in yields considerably in excess of those from untreated plots, and was achieved by spraying with parathion. Despite these results, the population of the white-fly vector at the end of the season was often high, and was thought to be supplemented from other sources as the species had a wide host range. A speaker from Ghana reported that the use of dieldrin against mealybugs as vectors of the swollen-shoot virus of cacao was only effective when diseased trees were cut out, although the spread of the disease was delayed by the use of the insecticide. Such treatment had to be followed up by cutting out latently-infected trees which subsequently began to show symptoms of attack. DR. C. J. MAGEE said that in 1939 attempts were made in Australia to control tomato spotted wilt by spraying against *Thrips tabaci* Lind. Unsprayed tomatoes lost fifty per cent. or more of the crop, but bait-sprays of tartar emetic and sugar reduced this to about thirty-three per cent. when used twice per week. When applied weekly, there was scarcely any gain. Spraying became general when DDT was introduced, and was now used freely, so that spotted wilt was unknown save in a few areas in New South Wales.

Dr. T. W. Tinsley suggested that the use of systemic insecticides should be of value whether persistent or non-persistent viruses were involved, or whether the vector was sluggish or rapid in its habits. On theoretical grounds, cacao viruses should therefore be well controlled.

Dr. G. H. L. Dicker announced that control of the leaf-hopper, *Macropsis scotti* Edw., combined with roguing, had given a marked reduction in the rate of new infections by the Rubus Stunt Virus in cultivated blackberries. The vector lived in the crop and was single-brooded, and control was best achieved during nymphal development. The annual number of new infections had now been reduced from 200 to ten per year per 2,000 plants, although control plots for comparative purposes were not available..

Another speaker broadened the discussion to include the spread of viruses underground. One of the problems in attempting to control nematodes was the fact that the eelworms lived at depths greater than could be conveniently reached for chemical applications to be made. *Xiphinema* spp. had been recorded at a depth of eight feet, and even at 2 feet they would be beyond the range of chemicals applied in the top six inches. Patches of soil infested by nematodes expand only slowly, so that chemical control would probably give lasting protection, and would be economically worthwhile with such cash crops as raspberries or strawberries even if not with tree crops.

Of the rate of virus spread by a vector, the Chairman pointed out that potato Y virus would survive for eight hours in a non-feeding Aphid, and that it could fly a long way in that time. Dr. Kennedy thought that the likelihood of transmitting to a similar plant was greater with the non-persistent viruses, and Dr. Watson said that Aphids migrating for a long distance were unlikely to be infectious. Dr. Broadbent pointed out that, nevertheless, an Aphid often takes a final probe and acquires virus before leaving a plant. Dr. Johnson said that whether migrating alatae would be infected depended on whether they fed as new adults or whether the virus could be transmitted from feeds made before ecdysis. He thought that in the bean aphid the new adult immersed its stylets before making its first flight.

DISCUSSION ON THE LINK BETWEEN RESEARCH WORK AND ITS APPLICATION IN THE FIELD OF PLANT PROTECTION*

Chairman: Prof. V. B. Wigglesworth, C.B.E., F.R.S., *University of Cambridge*

The Chairman opened the meeting by likening research work to a pyramid, of which the apex represented the problem and the whole was stabilised on a wide base of research information. If the field worker tended to consider the problem as a wide one, with research results as only one of the leads open to him, then he had turned the pyramid upside down with resulting instability. It was one of the tasks of the present-day entomologist, and others, to publicise the whole structure of research that lay at the base of applied work, so that its uses and potentialities would be appreciated by the grower.

The Links Between Research and the Grower in the Field of Plant Protection in Canada

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In Canada advisory services in agriculture are provided mainly by the provinces because responsibility for education was vested in them under the terms of the British North America Act of 1867. Although advisory services for agriculture were undertaken by governments early in the history of what is now Canada, these have been developed mainly during the present century. Each of the ten provinces now has well-organised advisory services in its

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* Joint meeting with the Sixth Commonwealth Mycological Conference.

Department of Agriculture to deal with production and other problems, including those in the field of crop protection, affecting the agricultural industry in that province. These provincial services, therefore, provide the principal links between research and the grower in Canada.

Although it does not have a primary responsibility for advisory services the Canada Department of Agriculture provides complementary advisory services in all provinces. Agricultural colleges, industrial companies, and growers' organisations and various other agencies and organisations also participate in agricultural advisory work. Although the organisation of advisory services differs from province to province, the key local figure is the district advisory officer, who is always on the staff of the provincial department.

Canada does not have a National Agricultural Advisory Service such as that in Britain and Wales (Jacob, 1958), nor does it have a co-operative extension (advisory) service such as that in the United States (Jones, 1958) in which federal, state and municipal governments participate. Yet, the services in Canada achieve essentially similar results in disseminating information and in applying it to the solution of problems faced by the agricultural industry. The usefulness and effectiveness of an advisory service depends on research to provide solutions for problems faced by agriculture. In Canada most of the agricultural research is done by the Canada Department of Agriculture. In the field of crop protection Glen (1956) estimated that about eighty-five per cent. of the research in entomology was supported by the federal department; the proportion is similar for research in plant pathology. The remaining fifteen per cent. is supported by provincial departments of agriculture, agricultural colleges, and other public and private research organisations. It is the responsibility of advisory services to apply the results from research from these and other sources to the problems faced by growers in Canada.

In the presentation that follows I shall first describe the provisions for research on crop protection problems in Canada, and then the various links in the chain between research and grower.

Research Services

The principal organisation engaged in research on agricultural problems in Canada is the Research Branch of the Canada Department of Agriculture. It has more than sixty composite regional establishments, with at least one in each of the principal soil, climate and crop areas of the agricultural regions in the country. Applied studies on insect pests and diseases affecting agriculture are conducted at nineteen of these stations. In addition, the Branch has ten Research Institutes for basic research on problems of broad national application. Four of these institutes devote most or all of their effort to research on insects and diseases. More than 300 scientists are employed by the Branch for research on problems in the field of crop protection.

The Research Branch was formed in 1959 by placing in it all the research establishments formerly in two Services, the Experimental Farms Service and Science Service. Previously research had been organised by scientific or husbandry disciplines in independent divisions having research establishments located in the principal agricultural regions of Canada, with administrative headquarters in Ottawa. As a result, joint research on a problem by staff from two or more divisions was arranged with some difficulty, and therefore tended to be the exception rather than the rule even when establishments of two or more divisions were at the same location. Now, staffs from several sciences are brought together in composite research establishments for co-ordinated comprehensive studies in as many scientific fields as may be required to elucidate and solve major problems affecting agriculture. Each establishment is essentially autonomous, with a director responsible for assigning staff and facilities to investigations of the problems of the region or subject and for the quality of the research.

Regional establishments are responsible for all aspects of applied research on the agricultural problems in the areas served by them, with special attention to comprehensive studies of crop, pest, or other major problems. They also provide essential regional services such as surveys, testing of chemical control measures, technical advice, and liaison with provincial advisory services. Some have special responsibilities for national problems.

In some regional establishments entomologists and other specialists are grouped together in a section based on a crop problem. For example, the Potato Breeding Section at the Research Station at Fredericton, N.B., has plant breeders, geneticists, plant pathologists, and physiologists, working together to develop improved varieties of the potato with resistance to its more important diseases and pests. However, in most establishments, entomologists and plant pathologists are still grouped in separate sections. But where this is done, co-ordination of effort and liaison between sections is readily achieved. For instance, at the Research Station at Lethbridge, Alberta, entomologists, insect physiologists, biochemists, geneticists, and plant breeders from three subject-matter sections are engaged in a broad study of the wheat-stem sawfly problem in which the development of wheats resistant to the sawfly with all other desirable agronomic characteristics is the main objective; other concurrent studies are under way to provide complete knowledge of the physiology, ecology, and host relations of the insect. The research establishment at Winnipeg, Man., also has entomologists, plant pathologists, physiologists, chemists, plant breeders and geneticists grouped by disciplines for comprehensive studies of problems in the production and storage of grain. Formerly these sections had been in four separate establishments, though with co-ordination of effort of plant breeders and plant pathologists in the development of rust resistant varieties of grain. Since these groups were brought together under a single director, joint studies on other problems have been undertaken with the result that more complete and more valuable knowledge of scientific and practical value is now being developed than would be the case with independent studies in the various sciences. Although the work at regional establishments is mainly applied research of immediate application by the industry, some more basic work on life-processes, etc., which develops more lasting fundamental knowledge of pest or other problems is also undertaken. Examples of such work are the studies on the genetic basis for resistance in wheat to the wheat-stem sawfly and cold hardiness in insects at Lethbridge, Alberta, host-parasite relationships of stem rust at Winnipeg, Manitoba, and the transmission of aphid-borne viruses at Fredericton, N.B. This work is done by research scientists who are not required to participate in work leading to immediate practical solutions for pest problems. However, much of the fundamental work on agricultural problems is now being centred at the Research Institutes where highly trained scientists and modern specialised equipment, that could not be provided at every regional establishment, are available.

Five of the ten research institutes are mainly or entirely devoted to research in entomology and plant pathology. The Entomology Research Institute, Ottawa, Ont., is the national centre for taxonomic studies of insects, mites and nematodes. It provides an identification service for research and advisory services throughout the country. It also conducts basic studies in genetics and physiology and on behaviour of insects, chiefly of biting flies and honey bees. The Entomology Research Institute for Biological Control, Belleville, Ont., conducts fundamental studies on the physiology and ecology of parasites and predators, and obtains and distributes natural enemies to aid in the control of introduced pests. The Insect Pathology Research Institute, Sault Ste. Marie, Ont., is responsible for similar studies of insect diseases. The Plant Research Institute, Ottawa, is responsible for taxonomic studies of fungi and seed plants and for other basic studies in plant pathology and physiology. It also provides identification services in its fields of responsibility for research and advisory agencies throughout Canada. The Pesticides Research Institute, London, Ont., conducts physiological and toxicological research on pesticides of all kinds and acts as adviser on pesticide problems for other agencies on request.

Statistical, chemical and engineering services are provided at Ottawa to give advisory services and do developmental work for Branch officers everywhere, respectively, on the design of experiments and analysis of data, the development of chemical and biological assays of pesticides, and of scientific or other equipment and methods. As consultants, these services are a major influence in improving the efficiency and effectiveness of Branch research.

A Scientific Information Section of the Branch collects and compiles scientific and other technical information and disseminates it within and outside the Branch, and assists in making new knowledge available to advisory services and growers so as to allow scientists to devote most of their efforts to their main research functions.

The co-ordination of the research of this diverse and extensive organisation is assigned to a headquarters executive of three officers, and a Programme Directorate consisting of one of the executive officers and of five Directors and fourteen Associate Directors. Each director has specific responsibility for a broad area of agricultural research and jointly with other directors for the co-ordination and development of the whole programme of the Research Branch. The field of crop protection is represented by a Director for Entomology and Plant Pathology; he is assisted by an Associate Director for each of the fields of entomology, plant pathology and pesticides. The Programme Directorate controls the programme through approval of the initiation and termination of projects, the selection and assignment of staff and facilities, and periodic reviews with the staff involved of problems within a region or on a particular subject. By these means the new organisation is gradually effecting more intensive, comprehensive and co-ordinated scientific investigations on important problems and reducing the effort devoted to less productive short-term *ad hoc* empirical studies. However, short-term experimentation and testing are still important in the Branch programme and will always have a place, but in future more and more of the research will be on broad problems to provide information of more lasting value. So far as possible new situations and problems in crop protection are anticipated, and investigations leading towards the development of control measures are often initiated well before the need for them arises or is evident to growers. Sometimes, however, growers or advisory officers bring new problems to the attention of the research workers.

Investigations of crop protection problems by provincial departments of agriculture are mostly devoted to field testing and demonstration of control measures, sometimes in co-operation with federal establishments in the area. The results are quickly made available to growers because advisory officers usually conduct these studies. A considerable amount of research, both basic and applied, is done by entomology and plant pathology departments of agricultural colleges and universities. Some of these are in support of, or supplement, federal researches. Practical applications of the results from these studies are quickly available to the provincial advisory service.

Federal Advisory Services

The federal department assists all advisory agencies in the country wherever it can, and engages in direct advisory work only in fields where it has a primary responsibility, as in many regulatory and administrative matters. It attempts to keep the public informed about its activities; and one of its chief objectives is to ensure that information arising out of the work of the Research Branch is made available to farmers either through provincial agricultural advisory officers or directly in reply to requests.

The main spokesman for the Department is the Information Division. It is responsible for all publicity issued by the Department. It arranges for the publication and distribution of advisory publications, the preparation and distribution of radio and television scripts, and of press articles on topics of current interest. It distributes a fortnightly press clip sheet on research and current pest problems, and other articles of general interest. It publishes and distributes to agricultural advisory officers and other technical agriculturists a quarterly, " Research for Farmers," in which the results of new research are presented. It also arranges for the preparation of motion pictures on pest or disease problems, as well as other agricultural problems, that are widely and effectively used by advisory and other services throughout Canada.

Most of the information thus released by the Department has been prepared by research officers and selected and edited for release by the Information Section of the Research Branch. This section also answers all inquiries from growers received at headquarters, and it collects, compiles, and distributes research information within the Branch and to other agricultural agencies.

An important unit of the Scientific Information Section is the Pesticide Information Office, which collects, compiles, stores and distributes information on the efficacy, hazards, persistence, and regulatory aspects of pesticides and their use. This is an important function, since much information on pesticides is developed by industry (and government establishments) and does not appear in print, or does so only after considerable delay. The Pesticide Information Office also evaluates data from all available sources to meet the responsibility of the Department for evaluating claims of manufacturers made in petitions for the registration of pesticides for sale in Canada. It also evaluates data on tolerances for pesticide residues to determine their applicability under Canadian conditions. It provides the principal liaison between manufacturers of pesticides and research, regulatory, and advisory services of federal and provincial governments. One of the more important results from the work of this office for both research and advisory services is that it gives assurance that chemical control recommendations are soundly based and that they do not contravene established residue tolerances. It also draws attention to lacunae in knowledge about pesticides and their uses under Canadian conditions, thus helping to ensure that studies required to fill these gaps in knowledge are undertaken.

The most valuable advisory services provided by the federal department are probably those given directly to the provincial services by individual research officers. In the three provinces that do not have provincial entomologists or pathologists federal research officers are the principal technical advisers to the provincial departments of agriculture on pest control policies and programmes. But in every province federal entomologists and plant pathologists maintain close contacts with provincial advisory officers and administrators and are frequently consulted about pest situations and control. They act on provincial spray calendar committees that in most cases meet once a year, and with other provincial, federal and university officers they review insect and disease problems and draw up control recommendations based on the latest research findings. These calendars or recommendations are then published and distributed to growers by the provincial Department of Agriculture. In addition, research officers often help to prepare publications on insects and diseases and they address general meetings and conduct training or refresher courses for advisory officers at the request of provincial and, sometimes, other agencies.

The Research Branch has stationed a livestock insect entomologist at Lethbridge, Alberta, by agreement with the Prairie Provinces. He is the only officer engaged full-time for advisory work in Canada on livestock insects. He assists the provincial departments of agriculture in the planning of control campaigns and promotes the use of control measures by demonstrations and addresses at livestock shows, fairs, sales, and meetings of livestock growers' associations. Elsewhere in Canada advisory work on livestock pests is done by advisory services of provincial departments of agriculture.

A liaison officer is employed at two federal research establishments for advisory duties in entomology and plant pathology, to reduce the load of such activities by research officers. Also, in some provinces, *e.g.*, Ontario, a provincial advisory officer is stationed at some federal research stations for the same purpose. Such arrangements are proving helpful, and it is hoped that similar arrangements will eventually be made at all research establishments engaged in research on crop protection problems. The principal advantages are that the liaison or advisory officer becomes much better informed about the research findings and also he can more readily bring to the attention of the research worker practical aspects of pest control that the latter might otherwise overlook. Although experience to date in this area is limited, there is some justification for believing that in future some arrangements along these lines will be made at most establishments doing research on pest control.

The aim of our Research Branch is to reduce direct participation of research officers in day to day advisory activities. However, research leaders will always have some responsibility in advisory work because the last step in research on control should often be the first in education. This is the testing of a new control measure on a field scale under the range of conditions to be found where it will be used. Such experiments require the assistance of advisory officers in finding suitable sites, supervising the field test and in evaluating results. At the same time these experiments serve as demonstrations for growers in the immediate district. It is an effective means of getting new knowledge into immediate use.

Other federal organisations than the Research Branch also play a significant role in disseminating information about pests and diseases and their control. Seed potato inspectors, registered seed inspectors, produce graders and inspectors, plant protection and quarantine officers, and other regulatory and administrative officers, who have frequent contacts with growers, frequently give information to growers and consumers on insect pests and diseases and their control. Because they keep in touch with research developments they are often among the more effective advocates of improved methods of control.

Provincial Advisory Services

Comprehensive advisory services in agriculture that make provisions for entomology and plant pathology are now provided by all provinces. Seven of the provinces have provincial entomologists and provincial pathologists or equivalent officers. Some of these are located in agricultural colleges and have some teaching duties. In all, the provinces employ some twenty-five entomologists and almost as many plant pathologists for advisory work. In addition, in those provinces with extensive acreage of fruit, vegetables and ornamental crops, much of the advisory load is carried by a staff of advisory horticulturists. Other branches of provincial departments of agriculture also participate in advisory work on insects and diseases and their control as part of their regular duties in promoting production or regulatory programmes and, as indicated earlier, research officers at federal establishments also serve in advisory capacities, especially where provincial services do not have their own entomologists or plant pathologists.

The key man in the organisation is the district advisory officer, known as the Agricultural Representative, District Agriculturist, or Agronome, depending on the province in which he works. He serves from 1,000 to 3,000 farmers and has an office in his district. He is responsible for all advisory activities in his district, including those concerning pests and their control. Since no advisory officer can have detailed knowledge in all fields of agriculture, he is kept informed by his headquarters and the Provincial Entomologist or Plant Pathologist on subject-matter and methods of disseminating it. In addition, experience from daily contacts with growers over the years also provides him with a background of knowledge about pest problems in his district. However, most of the information he uses is supplied by the provincial subject-matter specialists, research entomologists and plant pathologists in his province, or he obtains it from scientific and advisory publications. Where necessary, subject-matter specialists assist in the district programme by addressing meetings of growers. In general, the district advisory officer evaluates the information available and adapts it to the situations, needs, and resources of the farmers in his district. In some provinces a district board with representatives from municipal governments in the district and from local community agricultural committees has been established, and participates in planning and carrying out educational programmes on pests and other agricultural problems. These are especially useful when emergency measures are required as a result of unusually severe or widespread pest outbreaks. The organisation and operation of an advisory service along these lines has been described by Hutchison (1959).

Advisory programmes in the field of crop protection differ from province to province and even district to district as crops, pests, and agricultural practices differ, and they also change as pest problems change from year to year. These programmes are usually decided upon at provincial headquarters on the recommendations of the advisory specialists. In some provinces, *e.g.*, Saskatchewan, an advisory council composed of representatives from provincial and federal government agencies, the university or agricultural college, and growers' organisations, reviews situations and makes recommendations on action to be taken. Provincial headquarters of the advisory services then plans and organises the educational activities needed to acquaint growers with pest situations and how to meet them. It supplies district advisory officers with background information on pest problems, issues forecasts, often based on surveys by federal officers, and prepares advisory publications, posters. press articles and other literature for general distribution. It may arrange for specialists to address provincial, area, and district meetings of key municipal officials, advisory officers and growers. District advisory officers are brought together at least once a year for instruction and refresher courses at which provincial specialists and research officers from various fields, including entomology and plant pathology, and from federal establishments and universities present up-to-date information on pest problems and their control and on methods of disseminating such information.

In the dissemination of information about pests and their control the district officer is guided by advice provided by his headquarters, and the level of attention given is determined by the severity of the infestation and the knowledge and experience already possessed by growers. Where the problem is new and outbreaks are widespread and severe and growers are unfamiliar with control, or if control recommendations are complex, this may involve a series of meetings and the use of press, radio and television to outline the situation and how to meet it. In some instances this has involved detailed planning of the advisory programme at the provincial, district and community level, including careful planning of all cropping operations, as described by King and Vigor (1935) for the severe general outbreak of grasshoppers in Saskatchewan in 1933–34, and by Farstad, King and Glen (1944) for the control of the wheat-stem sawfly. Such control programmes have been successful, even under very adverse conditions, when they were well planned in advance, advisory and supervisory staff were trained, and municipal and community committees were set up to carry the information to growers. To ensure the success of such advisory programmes, charts, illustrations, slides or other visual aids, timely news items on pest development and control operations, and other articles outlining the problem and means by which control can be effected under various conditions of farm resources, soils, weather, crops, and degree of infestation likely to be encountered are essential. In such programmes advisory and research entomologists (or plant pathologists) must take leadership and convince provincial authorities that the programme is necessary and will be effective, and then they must provide detailed information on the situation and programme to the district advisory officers, and assist them in general meetings of local government officials, local community leaders and growers.

Local committees have repeatedly proved their effectiveness in the dissemination of information on pest problems and in securing adoption by growers of new control methods; they are used in some but not all provinces and could with advantage be used more generally since they enlist the active participation of the growers themselves in studies of pest problems and how to meet them.

Other Links between Research and Grower

The pesticides industry, pest control operators, companies that process crops grown for them under contract, retail dealers, elevator, transportation and other large firms, and grower co-operatives distribute much information about pests and their control in Canada. This is done by means of advertising, news letters, films, personal contacts, and field demonstrations by field and sales representatives. Most of the information disseminated is obtained from government research and advisory services. However, companies selling pesticides or pest control services tend to base their information on industrial research and experience, so naturally it has some bias for the product or service provided by the company involved. But, on the whole, the information supplied is reasonably objective and reliable.

In recent years some chemical manufacturers have employed technically trained specialists of high professional standards for liaison and promotional work and have provided complete and objective information about their products, and recommended only those pesticide uses that have been thoroughly tested and that have been approved by government regulatory, research and advisory services. This has gone a long way toward eliminating unsound and conflicting recommendations to growers.

Local dealers are another important source of information for growers with pest problems. The grower often goes first for information on how to control a pest to the dealer. Most dealers are not well informed about pests and their control and rely on spray calendars and the district advisory officer for much of their information. However, often the advice given is based on the information given on pesticide packages on his shelves. Advisory services and manufacturers could improve the value of this link between research and grower by providing comprehensive short courses in pest control for such dealers.

The services of pest control operators have been used relatively little by growers in Canada and then usually chiefly for the protection of special or canning crops and where aircraft applications of pesticides are needed to avoid damage by ground equipment to tall or maturing crops. Through their contacts with growers, pest control operators are helpful in bringing new and effective pest control into use by growers; and if present trends for such services to be increasingly used by growers continue, they will become more important in the applications of research to the solution of pest problems especially as control programmes increase in complexity.

Supervised control services, such as those that have been successful in California, and of which Ray F. Smith, Department of Entomology and Parasitology, University of California, was an early proponent, have not become available in Canada. These services provide an entomologist to a farmer or group of farmers to keep track of pest developments in the crop and to select and supervise all operations required for effective and economical protection of the crop from damage by all pests. The principal advantage of this service is that the grower, who usually has not the special knowledge that is needed, is relieved of the need to assess the pest problems and to determine what to do about them; at the same time he is assured that the control methods used will be based on all relevant information available. This has not yet been attempted in Canada. However, the regular notices issued by provincial advisory services on pest developments and timing of pesticide applications are a step in this direction. Eventually, especially in areas where special crops are concentrated, supervised control, directed by an entomologist or plant pathologist, thoroughly trained in all aspects involved in the production of such crops, offers a means of obtaining quick and effective application of research findings to crop protection. However, such developments appear to be some distance away in the future.

Progressive farmers have always had an important part in bringing about the general use of new crops and new methods. This is true of insect or disease control, and most advisory officers work with and through such men in promoting new methods of crop protection. When a new method proves successful for such farmers their neighbours soon follow their example.

General Remarks

In discussing the links between research and the grower in the field of crop protection in Canada one must keep in mind that research in this field is supported mainly by the Canada Department of Agriculture, and that it is organised and co-ordinated on a national basis with reasonably adequate provision for studies on important problems in every region of the country, whereas responsibility for promoting the use of the results of research in crop production rests with the advisory services of ten provincial departments of agriculture, each of which is concerned only with the problems affecting its own agricultural industry. There is no formal agency for the co-ordination or integration of advisory activities or programmes on a national or interprovincial basis; nor is there formal provision for co-ordinating research and advisory work. The rather informal and loose liaisons which are provided for the transmission of the results from research at federal establishments to advisory services are reasonably satisfactory though there is still much room for improvement.

The steady increase in the size of farms, mechanisation, and application of scientific principles to crop production in Canada, as elsewhere, is reaching the stage where many more highly trained advisory entomologists, etc., must be employed if the advances in knowledge being made by current research are to be incorporated into farm practice as quickly and fully as possible. Attainment in Canada of this desirable objective may be far in the future, but specialist staffs must be increased soon especially as general advisory officers cannot meet the demands of growers for precise and specialised knowledge in this and other fields. Another development already under way that will further increase the effectiveness of these links between research and grower is the secondment of advisory subject-matter specialists to establishments conducting applied research in their field. This has frequently been suggested by research officers and others, *e.g.*, Beaulieu (1959), Manson, Miller, Begg and Wressell (1959), and Glen (1959), but so far advisory specialists (*e.g.*, entomologists) have been stationed at only a few establishments. Where this has been done it is resulting in improved services to growers and has freed research personnel from advisory activities other than those required in drawing up recommendations on control and planning advisory programmes. The successes so far achieved provide a sound basis for recommending that advisory entomologists and pathologists be stationed as soon as possible at all research establishments concerned with applied research on insect pests and disease. It matters little whether they are provincial, federal or university staff, provided they are seconded to the establishment and that advisory and research programming is integrated as fully as possible.

In the near future more effort is likely to be devoted to integrating and co-ordinating advisory work concerned with pest problems into broadly based programmes in which all factors affecting crop production are evaluated, and those pest control practices selected that fit best into an overall crop production programme which takes into account not only the pest but also other problems and which achieves the highest return for the expenditure that can be made. As Ferguson (1958) has pointed out, this requires that different research and educational programmes must be undertaken to obtain the best solutions on the one hand, for the highly mechanised and specialised industrial type farms and on the other hand, for the family operated less mechanised small or marginal farms. In other words, advisory programmes should concentrate on the whole operation rather than on individual problems separately.

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The Links Between Research and Advisory Work in England and Wales

By MR. F. H. JACOB

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In England and Wales research and advisory work are administered in different ways, and before attempting to describe the links between them, I think I should try briefly to explain how our services work. There are three services that are designed to assist the farmer. Two of them, the advisory and regulatory services are the responsibility of the Ministry of Agriculture, Fisheries and Food; the research service is independent. There are nevertheless close links between the research and advisory sides, and one of them—the Agricultural Improvement Council—is an especially close one.

Research

Most agricultural research falls under the aegis of the Agricultural Research Council which is appointed by a committee of the Privy Council. It is not a part of our Civil Service. The committee of the Privy Council has as its Chairman the Minister for Science (Lord Hailsham) and its members are the Minister of Agriculture, Fisheries and Food and the Secretary of State for Scotland. In the House of Commons the Minister of Agriculture deals with questions on agricultural research.

The Agricultural Research Council provides most of the funds used in research stations and undertakes general supervision of their programmes; it finances and organises special research units, makes special research grants to universities and other bodies and awards post-graduate scholarships. I think we have been fortunate in the broadly liberal research policy of the Council—it prefers to guide rather than to direct, with the result that research workers enjoy a large measure of freedom in choosing their work.

Advice

The Minister of Agriculture is responsible for the provision of advice through the medium of the National Agricultural Advisory Service which is administered by the Advisory Service and Infestation Control Division of his Ministry. The Infestation Control Laboratory dealing with stored products and the Plant Pathology Laboratory are in the same Division. The latter is a liaison centre where some research is done; it works closely with the

Entomologists and Plant Pathologists of the National Agricultural Advisory Service, has other advisory and educational duties, and is responsible for the scientific side of plant health regulatory work.

There are two other duties of the Laboratory that fall under another Division. One, the activities concerning the hazards and precautions associated with the use of pesticides, has been described by Dr. Miller earlier in this Conference. The other is the Agricultural Chemicals Approval Scheme for insecticides, fungicides and herbicides. The Plant Pathology Laboratory is intimately associated with this work which is of direct and indirect value to the farmer in providing a link between commercial developments and the adviser. I must emphasize that both these schemes are voluntary and that their success depends on the closest possible co-operation and trust between industry and the Ministry. It is thought that the recently reorganised Approval Scheme will get over one of the adviser's real difficulties, namely the sudden appearance on the market of new pesticides that he knows nothing about.

The Agricultural Improvement Council

The Agricultural Improvement Council might well form the main subject of this talk, but I think my task is to try to explain some of the other links between research and its application. The Agricultural Improvement Council is a committee composed of leading farmers, scientists and officials appointed to advise the Minister of Agriculture. It has a most important job, its terms of reference require it ' both to see that the results of research are applied in practice and that the problems encountered in practice are referred back to those responsible for agricultural research.' These words are quoted from the third Report (1950–56) of the Council (1956), and I would like to emphasise this provision for the two-way passage of information. It is obviously as important that the research side should be well informed about the farmers' problems, as it is that the farmer should be informed of new developments.

There is a Joint Committee of the Agricultural Research Council and the Agricultural Improvement Council which ensures close liaison between the two Councils—or rather—three, because the Agricultural Improvement Council for Scotland is included. The link between the Agricultural Improvement Council and the National Agricultural Advisory Service is close at administrative level—its scientific officers belong to the National Agricultural Advisory Service—and Agricultural Improvement Council Committees supervise the programmes of the National Agricultural Advisory Service Experimental Husbandry Farms and Horticulture Stations. Research stations are given facilities to work at these centres and thus there is a direct link at the investigational level.

The National Agricultural Advisory Service

I think I should describe in a little more detail the structure of the National Agricultural Advisory Service. The Country is divided into eight Regions of which Wales is one. Each Region comprises a number of counties which are in turn subdivided into advisory districts in charge of District Advisory Officers who are general practitioners and in direct touch with the farming community. The District Officer is therefore one of the most important people in the service. It was the aim in 1946 (when the National Agricultural Advisory Service was born) that he should have about 1,000 farmers on his panel; but often he has many more. At county level, there are County Advisory Officers and a number of specialist advisers in particular facets of husbandry, and at Regional level there are husbandry and science specialists, including mycologists and entomologists. There are close ties between all branches of the service. One of the duties of the specialist officer is to investigate local problems which are often brought to his attention by the District Officers. This is research and a good deal of it is done by entomologists and mycologists. The headquarters of the service is in London, and its organisation is well described in a report on the first eight years of the National Agricultural Advisory Service published by H.M.S.O. (1955).

To summarise, we have on the one hand an extensive and intensive research service working in close liaison through the Agricultural Improvement Council with an advisory or extension service providing in addition to its basic function of giving advice, facilities for research, experiment and demonstration. The problems are: how are the results of research prepared and passed on to the grower, which is our main interest to-day, and how in turn are the scientists informed of the growers' needs.

I will have to take the first part of the subject in stages, although they are by no means clear-cut. Firstly, how research results reach the specialist adviser; secondly how he uses them and thirdly, how they are passed on to the grower. Recently, a senior Advisory Entomologist remarked to me that to persuade the grower to take advice is the most difficult problem of all. I will pay relatively little attention to the other half of the cycle.

Research Worker to Specialist Adviser

There is not a really clear-cut separation here in that the specialist adviser is, or should also be, an investigator. Perhaps, for the sake of argument, I might say that the adviser's research work tends to be more ' down to earth ' in that he is trying to find answers to specific locally or nationally important problems.

The usual means of communicating information are through the scientific literature which includes the Ministry's own journal, *Plant Pathology*, and the discussions of learned societies. It should not be overlooked that the meetings of such societies provide opportunities for the exchange of ideas that go far beyond their formal discussions. Fortunately, we are a small country and attendance at meetings is not really difficult, so that in a comparatively short time workers can establish personal contacts with others in their own field. There is no need for me to repeat what we so often hear about the literature, because you must all feel as I do, that there is too much for us to digest, and in common with many other scientists, I think many advisers feel the need for more and perhaps more specialised abstracting and review services.

The Ministry of Agriculture has its own means of supplementing published work and the activities of learned societies. Fairly recently, the National Agricultural Advisory Service started a loose leaf handbook containing up-to-date summaries of current scientific knowledge on many aspects of agriculture, including pesticides. This is supplied to all advisory officers. On a more limited scale, the Plant Pathology Laboratory provides entomologists and plant pathologists with ' Pesticide News Sheets ' summarising information on the very latest chemicals often not even available in this country. This information is often based on data kindly supplied by manufacturers.

Each group of specialist National Agricultural Advisory Service officers has its own conference which meets about three times a year. The plant pathologists and entomologists, in addition to holding ' closed ' or purely administrative conferences, hold two scientific meetings a year in London and one at a Regional centre where something is seen of local farming and investigation. The Plant Pathology Laboratory provides the chairmen and technical secretaries of the scientific conferences and in its liaison capacity is able to call upon research people to discuss their work, often in its relatively early stages. The Agricultural Research Council is represented at these conferences. Frequently, advisory officers are asked to describe their own work and in turn they may ask the secretaries to arrange discussions on subjects of general and special interest. I believe that this forum is useful and appreciated by all sides. I must add that arising from these conferences there has been and still is a certain amount of co-operative investigational work of which pest and disease assessment is perhaps the outstanding example.

Another valuable activity is the arrangement of formal visits to research stations by advisory officers, in particular the more junior people. There are annual visits for our own groups, but the larger ones have to limit attendance so that any one officer may be able to make such a visit only once every two or three years.

In addition to all this, advisers are certainly not discouraged from making personal contact with research stations and where an advisory centre and a research station are near to one another, the contacts are often very close. There is in fact a good deal of direct co-operation between the two services: an excellent example being the work on wheat bulb fly undertaken by Rothamsted and the National Agricultural Advisory Service regions where the pest is troublesome.

I don't want to leave you with the idea that we are entirely complacent about all this. There is undoubtedly room for improvement, but I will mention only one thing that may be common to other countries. It is that often the research worker is able only to carry out his work so far as his facilities and perhaps, abilities allow. This is not always up to the stage where the farmer can practice what the research preaches, and many of us feel that better facilities are needed for straightforward development work in which ideas arising from research can be tested as nearly as possible under the conditions of commercial practice. To some extent the N.A.A.S. Experimental Husbandry Farms and Horticulture Stations can do it, but they are not the complete answer.

Specialist to General Practitioner

At this level, information is exchanged mainly within regions, by means of conferences at which specialists describe recent developments in their subjects. Regional experiments are planned and demonstrations arranged for the benefit of advisers and the public.

There is also a good deal of written information of various kinds such as regional memoranda and newsletters; and one publication—the *National Agricultural Advisory Service Quarterly Review*—intended primarily for the District Officer. It is pretty good for other people too. It is of prime importance that information should flow freely at this level, and strenuous efforts are made to make it do so.

General Practitioner to Grower

The District Advisory Officer's job would really need a talk all to itself. It is difficult to define and is perhaps too obvious to need precise definition. He deals with the grower directly in the course of advisory visits, at meetings which are frequently arranged and at which specialists are often invited to speak, by letter and in the course of farm walks and demonstrations. In an O.E.E.C. report on Advisory Services in Europe since 1950 (1954), Dr. Paul Miller quotes Dr. Seaman A. Knapp, one of the founders of the U.S.A. extension service as saying—" what a man hears he may doubt, what he sees he may possibly doubt, but what he does himself he cannot possibly doubt." This principle is well recognised by the National Agricultural Advisory Service and by commercial firms, in fact it was followed long before the N.A.A.S. came into being and formed an integral part of our wartime effort to increase agricultural productivity. Exhibits at national and local agricultural shows are used to advertise new ideas, field demonstrations to show how they can be implemented and farm walks to show how progressive growers develop both their own and other people's ideas. Often, plots are sited near roads and conspicuously signposted so that farmers can stop and judge for themselves. This technique is popular with many commercial firms, especially perhaps seedsmen.

The District Officer is backed up by a good deal of special literature: bulletins on crops and livestock, advisory leaflets on pests and diseases of crops and stock, weeds, etc., and local bulletins or newsletters. Radio and television are used when the occasion warrants.

Information About the Growers' Needs

There is not I think any need to labour the point that the channels available for passing information one way are equally available for passing it the other. I will, therefore, mention just one aspect of the problem that I think could be greatly improved, namely pest and disease intelligence. I think it is important that the needs of growers should, wherever possible, be backed up by sound intelligence. During the past ten years under the leadership of our pest and disease assessment teams, we have obtained excellent knowledge of the importance of a few organisms, but nevertheless, our knowledge of the economic importance of pests in general is still pretty rudimentary. To put it shortly: we need to know very much more about pest ecology, and I would suggest that there is a great need for much more carefully planned long-term effort in survey and measurement. The casual collection of tit-bits of information, while often of interest and even value, is not enough. This is a big subject and all I have time to do is to suggest that anyone planning a pest or disease intelligence service, should first ask himself what information he wants and precisely why; and in setting out to get it, to make use of all the expert advice now available on the conduct of surveys. I very much fear that he will find that money and manpower quickly become the factors limiting progress.

Instead of summing up I will just try to condense one thought that seems to me important. If it has occurred to you that I have not concentrated enough upon our own subjects, I would point out that that is quite deliberate. Crop protection forms only one facet of the problem of improving the efficiency of crop production and cannot get very far without a degree of co-ordination with other disciplines and needs of agriculture. Thus, I would suggest that a basic requirement for a successful advisory service, is to provide sound and strongly supported general practitioners at one level and people with great breadth of knowledge and experience at the other to guide policy. It is no less important that research should be supported by breadth of agricultural knowledge.

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The Link Between Research and Application of Crop Protection Chemicals from the Manufacturer's Point of View

By Dr. G. Watts-Padwick

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The subject of the link between research and its application in the field of plant protection chemicals at once raises the question of where research ends and application begins. I shall not try to define this, because the distinction between the two is in practice not at all sharp, and I think where the two merge is well enough understood by those who are attending this Conference.

I do want, however, to point out that, at various stages in the development and application of crop protection chemicals, new problems emerge which throw back to the research worker what earlier appeared to have been fully solved problems. Research may still be continuing on some aspects of a project at a time when other aspects have already reached the development or application phase. This is important if you are talking of the link between research and application, and for this reason I am not talking today of the sharp distinction between the two that might be signified by a " link," but rather am anxious to deal with the overall subject in a general way, indicating how in various aspects research and application are fused at a number of different places. There is in fact no such thing as " a single link " between the two, but rather there are multiple fusions.

I propose therefore to speak first of the technical aspects, then commercial, administrative and financial, before commenting finally on what I believe the future trends to be.

The technical problems involved may be divided into biological, chemical, medical and mechanical.

The biological problems start with the selection of the targets. Here the industrial research worker starts from a different base from that of the Government administrator or University research man. He must select his targets from the point of view of their overall or global importance. The reason for this is quite simple, namely, that the expense of developing a new chemical has become so high that any individual concern setting out to solve a minor problem might well meet with financial disaster. The targets must therefore be selected with a view to their world-wide importance, although it is recognised that sometimes the products discovered will ultimately be developed for purposes which are different from those originally selected.

Having selected the target, which is based on a study and knowledge of world pests and diseases, the search begins for chemicals which have the required properties. Some companies today have a screening system whereby they can test many hundreds and possibly thousands of chemicals a year for general insecticidal, fungicidal and herbicidal properties. We, in Plant Protection Limited, look particularly however for indications of specificity. It is widely held today that the chances of finding a replacement for general pesticides with qualities comparable with DDT, BHC, 2,4–D, MCPA and so on, may be small, and that success is more likely to be achieved with products showing a higher degree of specificity.

Once a chemical has been found which has one of the properties sought, a next step is phytotoxic studies. I need not elaborate on these as they are so obvious and it is equally obvious that a product showing, shall we say, insecticidal properties, may be ruled out because of its phytotoxic characteristics. It might be thought that in such cases the product would be useful as a herbicide, but this does not necessarily follow, and I do not think that herbicides have generally been found by accident in phototoxicity tests.

Under the heading of biological problems must also be mentioned preliminary mammalian toxicity studies. I am not suggesting here the elaborate medical investigations which have to be carried on later, but it is important that at an early stage a product which is extremely toxic to mammals should not be pursued at great cost, only to be rejected ultimately. To be on the safe side in screening tests we assume unknown chemicals may be toxic to man and take suitable precautions.

From this point onwards, that is, from the time when a chemical has been found to have crop protection potentialities, is acceptable from a phytotoxic point of view and has only moderate to low mammalian toxicity, we can begin to test it throughout the world on a range of crops and pests depending upon the degree of specificity already mentioned and upon the target for which it was invented.

Alongside the biologists in any modern industrial crop protection laboratory, chemists are working in close liaison. Their work may be based on either " shelf lifting," that is, the screening of a wide range of chemicals which have come more or less by chance from the various laboratories in a big chemical manufacturing company, or they may be the result of synthesis deliberately aimed at building a chemical with certain groupings which it is believed may influence its toxicity to insect pests, fungi or weeds. Whilst it is true that these two approaches are nowadays going hand in hand, it is probably also correct to say that greater emphasis is being laid on a more constructive type of approach than was the case a decade ago and less on complete chance through the indiscriminate testing of a large collection of unrelated chemicals.

The discovery of the fact that a chemical possesses anti-biological properties is only the beginning for the chemist as it was for the biologist, for at once the chemist must start not only synthesis of related chemicals but also devising preliminary formulations for testing purposes. At this early stage the formulation problem may be a comparatively simple one, such as dissolving in a solvent like acetone and mixing with water so as to apply it to the plant in sufficient dilution.

As soon as preliminary formulation work begins, problems are likely to arise on corrosion of manufacturing plant, containers and machines and related troubles which in the laboratory may be of little significance, but which later may be a deciding factor on whether or not a particular chemical can be used in agriculture. To the formulation expert also come such problems as stability, shelf life and compatability, for in these respects there are wide opportunities for a chemical to misbehave once formulated; the problems of phytotoxicity and poison hazard, at one time thought solved, may again raise their ugly heads.

Having found a chemical, formulated it on a laboratory scale, checked such problems as corrosion, shelf life and so on, the chemist now comes to the point of pilot scale manufacture and the development of an industrial process for the active ingredient and the formulated product. This is in itself a huge field of research and development which is thrown direct at the industrial chemist, physicist and engineer.

I mentioned before that preliminary mammalian toxicity studies take place at an early stage. However, once a chemical really begins to look promising there must be a big intensification of the work on human and animal toxicity into which the medical man must be brought. It has been stated by more than one authority in the U.S.A. that to obtain the approval and registration of a chemical from this point of view costs up to $1,000,000.

Having discovered the safe chemical, formulated it and found how to manufacture it, there comes the question of applying it to the crop. No matter what work may have been done on formulations, it is often found that those developed in the United Kingdom are not suitable for other parts of the world. It may for instance be necessary to increase the concentration of the formulation in order to reduce the cost of transport, even though the original cost may be higher; or to formulate so as to meet high or low temperatures and humidities. It will also have to take into account the types of machine which can be used and these depend upon the way in which the crop is grown and the abilities, the resources, the education and the intelligence of the farmers.

It is, of course, useless to supply chemicals and machines without arrangements to maintain the machines in good working order. This has in our experience been a major problem in many countries in the world, but it is not an insoluble one. There are today in the tropics many, many thousands of small motorised machines working successfully and maintained by central service stations usually operated by a Government Department of Agriculture.

We now have to consider certain aspects of the work which cannot be classed as research, but which are development stages equally important to the welfare of the project as a whole.

A company before it decides to sell a chemical in any particular country for crop protection purposes must make a study of the economic factors involved—that is to say, what the crop is worth, what are the losses, what area of crop is likely to be involved, how much the increased or improved produce is worth, how the farmers' purchases will be financed, and a multitude of related questions. Having worked out these economic sums, a sales forecast is made to see what supplies will be required and what techno-commercial effort should be put into the project. A system for supplying the product and distributing it so that it can reach the remotest farmer then has to be designed. The product must be sold in the right packages, often with suitable measures, and always properly labelled. Plant Protection Ltd. has at the present time twenty-eight different sizes of package for the export trade alone.

Publicity is a vital matter, and we have found it necessary to set up a publicity section which has the responsibility of seeing that the information provided is not merely attractive sales literature, but also technically and ethically correct. Our agents throughout the world are provided with technical data sheets and are given detailed and carefully drafted technical instructions before the product is launched. Leaflets and labels must be accurate, and of course must be in the proper language, using local terminology for weights and measures—not a small matter when our products are being sold in over eighty countries. The label on the package, be it ever so small, has legal significance and must provide in pocket edition all the most essential parts of the information, so that the farmers are unlikely to make mistakes. It must give adequate warning if there is a poison or phytotoxicity hazard.

The work involved is substantial. Plant Protection Ltd. have at present 500 different labels in the export market and twenty-four languages are used in the printing of these.

With the immense amount of effort that has by this time gone into the development of the product, it is not surprising that most industrial concerns will be anxious to patent it and to provide and register suitable trade names, thus protecting their own interests. The patent position is of course looked at from the moment that a chemical is discovered to have any anti-biological properties worth considering, but it can take a very long time for the patents to issue, and the end result is not always considered satisfactory to the management of a commercial crop protection chemical manufacturing company. To ensure that the protection is as effective as can be reasonably expected requires a staff specialising in patent law—either legal men with an understanding of chemical matters or chemists with a flair for patent law.

I think it is appropriate that I should say a few words about financial aspects of the development of chemicals; you would not want me to go into details, but I have deliberated somewhat on the various sciences and techniques which have to be applied in the developing of a new chemical. My own company recently produced a herbicide and desiccant with very striking properties and introduced it to the market only a few weeks ago. The cost of research and development of this product, before paying for a full-scale production unit, is estimated at £½ million. Most American companies put their average costs of developing a chemical at a considerably higher figure.

Industrial concerns naturally expect to have to pay the cost of developing chemicals and are prepared to do so, but plenty of scope remains for Government Departments to conduct their own work and to foot some of the bills. The ultimate testing of the chemicals, for instance under an infinity of varying local conditions, is beyond the resources of even the largest industrial concerns, and it becomes necessary to invoke the help of local Government experts and research stations in carrying out field tests. Our experience is that Government research workers are almost universally co-operative in this matter, but they do not always get as much financial backing as seems necessary for the work to be undertaken on a big enough scale.

In many countries Government aid to the user is being adopted as a means of introducing him to crop protection chemicals. Many of you will have heard arguments against this because it seems to be a form of subsidy which, under a system of free enterprise, should not be necessary and is merely making people dependent upon the Government. In fact, we have today moved so far away from the so-called natural economic factors, that to introduce a subsidy is not making the grower unnecessarily dependent upon the Government. Rather the latter may be paying him back what has been taken from him in some form or other, as tax or cess on his crop. At any rate, it is sometimes found that where a subsidy or loan is applied, really big developments take place to the advantage of the individual growers and the country as a whole.

No commercial concern could offer to provide the organisation which should be given by an Agricultural Department of a Government, and even if it were possible, it would in many countries be considered objectionable on political grounds for it to do so. In some countries the Government organisation on behalf of the user has now become great and efficient, but others still have a long way to go. Here again it is necessary to combat the bogy of artificiality and alleged feather-bedding of the producers.

It is just as well to remember that today most countries are exporting one or more agricultural products, usually in very strict competition with one or more other countries, and often these goods must provide the foreign exchange needed by the country for its life or development. Therefore it is not good enough to treat such agricultural industries as though they were nothing more than a picturesque way of life; they must be organised with efficiency like any other industry, and are equally entitled to support and protection by the Government.

Generally speaking, private commerce can be expected to operate more efficiently than a Government Department in such matters as supply and distribution, but where a Government prefers to do this itself, it can expect to find a manufacturer co-operative. Another matter in which industry can often help is over machinery for applying the chemicals, to establish and operate machinery maintenance depots. My own company has from time to time lent the services of individuals and even teams of men for periods of a year or more.

I have mentioned the high cost of producing a new chemical which will meet the exacting demands of Governments and farmers today. The simple and common chemicals have been thoroughly worked over, and it can only be expected that developments will go to those concerns which set up a very substantial team of research workers including biologists, chemists, medical men and engineers as well as commercial, administrative and financial and legal experts. When all this is done, there remains the final responsibility of the Government to conduct local research, to advise and protect the local grower. In the circumstances, it is not surprising that industry looks to Governments to finance their side of the work and it is to be hoped that in the future, as more and more chemicals are discovered having highly specific and valuable properties, the Governments will provide enough funds to ensure that they are used to the fullest advantage.

Plant Protection Research and its Application Under the Diverse Agricultural Conditions of Kenya Colony

By Mr. A. R. Melville

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Following speakers who have described conditions in larger territories and organisations, I am now going to tell you something about the position in a relatively small overseas territory where agricultural conditions are in some respects unique. To provide the appropriate background, I think it would be useful to commence this talk with a very brief general description of Kenya so that listeners will be able to understand more clearly the great range of conditions under which agriculture is practised in the Colony; conditions which produce a wide range of problems for our plant protection staff who serve both African peasant farmers whose cultivations are limited to smallholdings and other farmers and planters who are able to operate on a more extensive scale. I will show a small number of coloured slides to aid my description.

Kenya lies on the equator and conditions vary from fully tropical on the East African

Coast at sea level to permanent snow on the summit of Mount Kenya less than 300 miles from the sea and at over 17,000 feet above sea level. Agriculture in one form or another is practised from sea level to over 9,000 feet but a large part of the country is arid and either totally unsuitable for any form of agriculture or sparsely occupied by nomadic pastoral people whose chief problems are water and grazing for their stock. Much of this class of land abounds with game. Where the rainfall is more favourable these areas give place to land where ranching can be profitable and semi-arid areas where some arable farming can be practised. To the west, Kenya bounds with Lake Victoria (3,700 feet) and the neighbouring territory of Uganda. This western region receives good rainfall and, although soils are generally poor, the vegetation is much more lush. In the main central highland mass one can make a single division between medium altitudes where maize is the main cereal crop and higher elevations where this gives place to the temperate cereals, wheat, oats and barley. In some places, irrigation schemes are being developed to settle landless Africans on small irrigated holdings and these, as might be expected, produce their own plant protection problems.

Coffee is grown at medium altitudes; tea generally above the coffee and pyrethrum at elevations of 7,000 to over 9,000 feet. Sisal grows under a wide range of conditions from medium elevations down to sea level—generally in areas of poor soils and low rainfall. These are the principal cash crops which are being grown by farmers of all races. Many other food and cash crops are grown commercially, *e.g.*, coconuts, cashew nuts, sugar, citrus, tobacco, a wide range of horticultural crops, sorghum, millets, beans, cotton, and in addition there are stock-farming interests in beef production, dairying, pigs, sheep and poultry. Every section of the agricultural industry has an interest in grass and very good progress is being made in research and its application in this field.

Against this wide agricultural background a wide and varied array of pest, disease and herbicide problems arises against which the technical resources at our disposal must be pitted. I must now give some account of what technical resources are available.

The Kenya Department of Agriculture is divided into two main divisions for its field and research activities. The former includes a small but growing section devoted to agricultural education which has great relevance to the theme of this talk. It is with the research division that I am personally concerned and I have been in charge of it for the past four years. We employ eight entomologists and eight plant pathologists. The research carried out is of an applied nature but most officers find themselves in the position of having to conduct some fundamental research and they must often, in addition, be prepared to take their work as far as application in the field or at least a considerable way towards this for the simple reason that unless they do so the results of their findings might never be applied at all. While this may not be an ideal arrangement it does have the advantage that it ensures that the research is on a sound practical footing. It must obviously not be taken too far, however, and extension beyond this initial point calls for the fullest cooperation from field officers.

Agricultural Officers are very busy people and, while excellent relations have been built up between research and field officers who work as a departmental team, they have many other important duties. Similarly, professional research officers cannot spare very much time to pass on their recommendations to field officers. For these reasons control measures are often taken up by farmers much too slowly. This is, of course, a generalisation, but entomological research officers in East Africa have been agreed for a number of years that the only way to solve this difficulty is to appoint technically trained extension officers for plant protection work as an additional and very important link in the chain. Even if they agree with this conclusion Governments have so far been unable to provide finance for this purpose. This is one of the biggest bottlenecks in our work and I shall be glad to hear the views of other delegates on this question. There is hope for the future as far as the African farmers are concerned in that the growing number of Africans who are receiving higher technical training should be able progressively to assist in this field. The need is great in Kenya because of the very wide range of problems that confront us but I am convinced that it is a matter of general importance in Africa and elsewhere and the technical training of this type of officer is one to which plant protection authorities in the Commonwealth should give very serious thought. In my view it is as important to get the knowledge we possess today into practice as it is to acquire new knowledge. The potential benefits to be gained are so substantial that it must surely not be long before steps are taken to remedy present staff deficiencies. Another field where additional assistance is required is that of scientific assistants for research workers for duties in the laboratory and for experimental work in the field. This group is reasonably well provided for but more work could be carried out by research workers if an extension of staff in this group could be achieved. In the more strictly research field our research officers receive valuable assistance in some branches of their work from regional research organisations such as the East African Agriculture and Forestry Research Organisation, the Empire Cotton Growing Corporation and the Colonial Pesticides Research Unit, the staffs of which are not so involved with the day to day problems of individual territories and have thus a better opportunity for more fundamental work. In order to achieve the application of research in the field it is essential to establish a clear chain of responsibility from the fundamental research worker through the applied research worker, the specialist extension officer, and the agricultural officer to the farmer. I like to think of the links of this chain as runners in a team relay race where the all-important transfer of the baton at the end of each leg may require a variable amount of overlap running. I have tried to show where this chain needs strengthening and if these needs can be met I would say that the level of our own research staff is reasonably adequate for the present stage of our development.

I should now like to contrast the problems and methods of putting across results of research to farmers in European farming and African peasant farming communities.

Broadly speaking, one can say that the acquisition of basic knowledge of a problem is unaffected by the sphere in which that knowledge might be used but that at the applied level it is frequently necessary to use a different approach depending on the end point one has in mind. As an example, there is a considerable difference between what can be done on a modern coffee plantation of several hundred acres and what can be done by an illiterate peasant farmer with 250 trees who may only be standing on the threshold of agricultural advancement. In this talk I do not have time to deal at length with the problems of extension work for European mixed farmers and plantations but can state with confidence that we are as advanced in this field as most other well-developed countries. We maintain a regular flow of extension literature, broadcasts, farmers' days on farms and research stations and, most effective of all, visits by departmental officers to the farmers themselves. In Kenya, this section of the community is much easier to get at, the number of farmers involved is relatively small and good progress is being made in applying the results of research. The African population is a different matter. Here we have to contend with a very large number of individuals on small farms and it is here that we need specially trained extension officers.

Under the Swynnerton Plan for the development of African agriculture a great agricultural revolution has been taking place in Kenya and a large team of very devoted officers has now been at work for several years. All our visitors are very impressed with these developments. These officers have such an enormous amount of work to do in connection with land consolidation, farm planning, development of cash crops and generally the fundamentals of better farming, that they have had little time to spend on plant protection matters. This is a matter which needs much more consideration and I am sure it will progressively get more attention as the more basic problems are resolved. Good progress has already been made in certain directions. For example, African coffee growers are using diazinon to control leafminers; malathion to control *Antestiopsis*; dieldrin to control *Coccidae* by banding; dieldrin to control White Stem Borer (*Anthores*); copper sprays to control Leaf Rust and prevent leaf-fall; and copper sprays to control Coffee Berry Disease. Pest control work is carried out by spray teams organised by cooperative societies, which consist of local groups of growers aided by field officers who receive advice from our research officers. Simple manually operated equipment is used.

There is interest in controlling *Thrips* in pyrethrum with DDT again through the Co-operative Society Organisation. In a number of areas maize stalkborer is controlled by hand application of DDT dusts.

It should be specially noted that the most encouraging results have followed the introduction of high-priced cash crops and that the application of plant protection measures has been greatly aided by the Cooperative Society Organisation. Extension literature, even when in vernacular languages, has not so far had much influence but will doubtless come to take an important place.

Talks, courses, posters, and broadcasts are beginning to show signs of usefulness but I would emphasise that we are still very much at the beginning of the job and that many difficulties lie ahead. Let me give you an example of the type of situation which confronts us. Maize is the main subsistence and, in some places, cash crop of the African farmer. He grows thirteen million 200 lb. bags per annum. He sells one million bags, consumes ten million bags and loses two million bags to insects, rats and moulds. This represents a loss to the farmer and the country of about £2,000,000 per annum. This loss could be prevented; we know how to do it; but so far only a very few advanced African farmers use cob and grain dusts. This single typical case exemplifies the need for a greater extension effort and it is one, incidentally, in which scope for action is not so dependent on the advent of more progressive farming in the field and in which it should therefore be relatively easy and straightforward to make progress.

Let me conclude with a brief consideration of the future prospects of plant protection in peasant farming. The present agricultural revolution in Kenya will produce in place of the old pattern of fragmented holdings, consisting of widely scattered plots with insecure tenure, consolidated holdings on which the African farmer can begin to practise better farming methods and develop a real appreciation of his importance on the land in taking his people away from subsistence agriculture. These farms can be planned and operated not only to produce better food crops and animal products but valuable cash crops suitable to the local conditions. A higher cash economy will be a greater incentive to the owner to take a greater interest in his farm. It is when this stage is reached that we are finding that the peasant farmer becomes more receptive to new ideas and there is no doubt that a much more rewarding outcome to our efforts to put over plant protection methods can then be expected. This has been our experience in Kenya.

I think that the Cooperative Society Organisation will continue to play a very important part for a long time to come but I also feel that as the number of good individual farmers builds up they will become increasingly capable of carrying out pest and disease control measures by themselves.

In Kenya, as far as the African farmer has been concerned, it has thus been a question of doing first things first; by this I mean that until one has improved the fundamental basis of peasant farming one could not expect to obtain full benefit from the application of plant protection knowledge, or indeed to demonstrate any advantage from its application in some problems. Under the old regime the African has been apathetic about the adoption of new methods. He has had no real incentive to do more than meet the minimum needs of himself and his family. He is, however, rapidly awakening to the conditions and needs of the modern world and if he is to achieve a better standard of living, *e.g.*, more education, better medical facilities and more material possessions, the old order must change. Signs of progress are real and strong but even today the majority of farmers still live in the old way and with these the first steps have still to be taken. Such simple basic practices as pure-stand planting of crops, early planting, efficient weeding, use of manures and fertilisers must often be adopted before the peasant farmer can afford plant protection measures or can reap full benefit from them. All this will take time. We have made a good start but without question Kenya needs all the help that British technical aid can give it to sustain the agricultural revolution now firmly under way, and it will continue to need it for a very long time to come. Workers in the field of plant protection can look forward confidently to a future in which their knowledge will be accepted and applied by African farmers with enthusiasm. With the steep rise in population that has followed the bringing of civilisation to the country there is a paramount need to intensify farming methods. There is no other answer. In this process the science of plant protection will play a prominent and very important part.

Problems of Plant Protection Extension Among Peasant Farmers in West Africa

By Mr. F. A. Squire
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Up until well into the 1940's entomologists and plant pathologists in West Africa were in a sense pioneers in a vast region whose plant pests and diseases were little known. Consequently they devoted themselves mainly to collecting and recording, and much of the general information gathered during that period is proving of great value in plant protection work today. In the course of their travels they naturally came into contact with many peasant farmers even in very remote places. Sometimes it was possible to give useful advice, generally based on ecological principles as chemical control was beyond the reach of the farmers.

There were many difficulties to contend with. In the first place the number of specialist officers was very small. In the whole of the West African sub-continent there were probably not more than a couple of dozen of them. In so vast a country as Nigeria there were at times only one agricultural entomologist and one plant pathologist. This paucity combined with the usual ups and downs of the service, such as illness, leaves, transfers and so on, led to considerable discontinuity and wasted effort both in the field of research and in extension work among the peasant farmers. Research projects were often a matter of individual taste rather than settled policy so that they were interrupted or discontinued according to movements of personnel. Field contact with peasant farmers, although it penetrated into isolated parts, was, in fact, too infrequent and too tenuous to do much good.

This could be met to some extent by working through extension officers who were strategically deployed. But these were also rather thin on the ground and were moreover much taken up with their own problems. A good way of making contact with the farmers was by attending " farmers' days " organized by agricultural officers from time to time and giving talks or demonstrations on plant protection methods. These were generally well received by the farmers who were always interested to know more about the pests and diseases afflicting their crops even though the means of controlling them was for various reasons out of the question. But perhaps more important was the establishment of cordial relationships with the farmers. The meetings were usually most enjoyable occasions. It was a gala day, and everyone turned out in his best clothes and most affable mood.

Another difficulty was the lack of suitable insecticides. Arsenicals as stomach poisons and nicotine concentrates as contact insecticides were the order of the day. They were too dangerous to be let out of sight for fear of accidents through carelessness or because they provided such a handy means of settling old scores between enemies. In any case, they were expensive and not generally on sale in up-country stores and the machinery for applying them quite beyond the means of the farmer.

Poor communications presented a serious obstacle. Letters were slow. Telegrams nearly always created confusion and despondency. One went about mostly on foot. No doubt the exercise was health-giving, but the cost in time was enormous. Hammocks were sometimes available but no fit officer would be seen in one. Occasionally a chief would lend one a horse but they were to be avoided on account of their inconsiderate habits. These visits were nevertheless worth the time spent on them, especially in so far as they could be made to raise the prestige of the more progressive farmers in the eyes of their own people, by setting them up as examples to follow.

The low standard of health in those days was undoubtedly a bar to progress. Many of the farmers were obviously too busy coping with their own maladies to bother much about plant pests and diseases. Malaria, dysentery and other endemic afflictions took heavy toll. There was a pall of apathy and fatalism especially in regard to malaria, when often the mosquito-breeding sites could easily have been controlled. This attitude of mind was also common in European communities so that it was difficult to obtain concerted action. Among peasant farmers it was worse. There was a tendency to make a virtue of apathy by reference to the inscrutable will of God.

But perhaps the biggest problem of all was, and still is, the system of land tenure. The land belongs to the tribe but family usucaption rights exist and this has led to fragmentation to an uneconomic degree. Even the individual trees may have different owners. In these conditions of multiple ownership it is often difficult to obtain agreement to any schemes for improvements. Consequently much of the agriculture has sunk to the level of bare subsistence farming so that there simply is no money to spend on controlling pests and diseases. But even if there were, cultural methods are often so poor and yields so slight that in any case it would not pay to apply plant protection methods. Good cultural methods are of paramount importance yet they are seldom achieved under this system of land tenure.

Present-day conditions are rather more favourable for agricultural development, at all events in the more advanced cocoa-growing regions. Financial and technical aid made available to West African Governments under various schemes to under-developed countries, plus the long run of high world commodity prices, have given rise to great expansion of research services. There are now in West Africa three research institutes each devoted to a single crop. The Federal Agricultural Research Department in Nigeria embraces a wide range of crops throughout the Federation and research is also carried out in some of the colleges. In addition regional ministries of agriculture have set up research organisations to deal with problems of local and immediate importance. Consequently there is a better reservoir of knowledge to draw on and more expert advice available to the farmers.

Paralleling this there has been an enormous increase in extension services, and consequently there are many more officers available to demonstrate plant protection methods to the farmers and to assist them in their difficulties. A feature of this break-through is the number of African officers holding positions of responsibility. They have a first-class knowledge of local conditions and are therefore the better able to deal with the peasant farmers whose language they generally speak.

Under the new political regime there is also a clearer and bolder lead being given by ministries of agriculture than has ever been known before. More positive and dynamic policies have been defined and there is a general air of urgency and immediacy. There is an electorate that demands action.

This new spirit is reflected in the farming community. Traditional tribal and quasi-spiritual ties have yielded to wider allegiances. Power is passing from traditional rulers into the hands of democratic governments with a Western outlook. It is no longer dangerous to acquire wealth. The profit motive is evident and peasant farmers are only too eager to grasp new ideas and techniques that appear sound and profitable. In this receptive mood it is comparatively easy to introduce new plant protection methods.

The contact between extension officers and peasant farmers is helped by a number of favourable circumstances. West Africa has never enjoyed such a high general standard of health as it does today. This is taken for granted by the younger generation but those of us who remember the bad old days can only marvel at the health and vigour of the farmer today. Greatly expanded educational facilities for both sexes through schools and other means of public instruction, including television, have given an edge to the thirst for knowledge that stamps the rising generation. Further impetus has been added by improved communications and the establishment of catering rest-houses at strategic points which enable extension officers to cover their districts more effectively. In this way they can help the farmers to obtain insecticides and fungicides and machinery and show them how to mix and apply them. This is greatly facilitated by the appearance on the market of handy-packaged chemicals and well designed compact applicators which are easily transportable in light vehicles. The preparation of sprays, formerly so troublesome, is now easy and fool-proof. Machines, too, are now simple and practically trouble-free. These are undoubtedly big factors in stimulating the sale of plant protection chemicals. Manufacturers would do well to study the problems on the spot and adapt the formulation, design and packaging to suit West African conditions. In the field of applicator machinery there is even more scope in this direction. It is well known, for instance, that Africans handle tools differently from Europeans. Movements that appear easy and natural to us are excessively fatiguing to them. These minor but important differences in musculature could very profitably be studied.

A striking feature of the modern agricultural picture in West Africa now beginning to emerge is the drift away from peasant agriculture pure and simple. This is of great importance in plant protection work because it overcomes many of the problems arising from the fragmentary system of land tenure and subsistence farming. Development corporations, farmers' co-operative societies, company assisted ventures, land settlement schemes and, yes, even private enterprise, these are some of the ways in which an escape is being sought from the prison of peasant agriculture. The present system of land tenure and farming is ill-adapted to the high-speed world of today.

These new developments not only favour progress in the field of plant protection; they demand it. Their success may depend on it. Development Corporations range from the giant ventures in the Cameroons to much more modest undertakings by regional governments.

Although these schemes are not based on peasant farming they exercise a strong influence on the countryside. Local farmers are quick to imitate where they can, and often enjoy the benefits of the expanded markets created by these corporations and their associated manufacturing and processing local industries. The same applies to the growing number of commercial agricultural ventures. Land Settlement schemes on the Israeli pattern are enjoying a vogue at present in some parts of West Africa and their number is rapidly increasing. What permanence they will achieve may be problematical but there can be little doubt about their beneficial influence on the young participants. Farmers' Co-operative Societies are playing an important part in agricultural development, and have the striking advantage that they help to off-set the effects of the fragmentary system of land tenure. They have been particularly successful in the field of plant protection in arranging for the financing of the purchase of machinery and chemicals.

The outstanding success of the chemical control of black-pod of cocoa in Nigeria, followed by the equally successful chemical control of Mirids (and, incidentally, it now appears, the effects of swollen shoot) has had a tremendous impact on the peasant farmer and made him nothing if not spray-minded. All this together with the appearance on the market of reliable low volume portable motorised sprayers have helped to popularise modern plant protection methods. In sharp contrast to what obtained in the past, equipment is now readily obtainable locally and most of the more important manufacturers of plant protection chemicals have on-the-spot representation, and even carry out their own trials on peasant farmers' crops. It is estimated that there are in the hands of peasant farmers in Western Nigeria alone nearly 100,000 mechanical sprayers of various types. Some 70,000 farmers have been trained by Government as spray operators. The training teaches correct plant protection methods and leads to the possession of a certificate of competence which is a great help in obtaining financial assistance for the purchase of machinery and chemicals. In Ghana events took a different turn. As in Nigeria, the Mirids, *Sahlbergella singularis* Hagl. and *Distantiella theobromae* (Dist.) were successfully attacked with BHC but the scheme was carried out not by the farmers themselves but directly by Government. One cannot help feeling that it is only right that Government should do something for the cocoa farmer in return for the very large slice of the chocolate cake taken by the Treasury.

Here it must be emphasised that there are many levels of agriculture in West Africa. Most of the progress in the control of pests and diseases reported above apply only to cocoa farming. The reason is not far to seek. By spraying effectively with copper fungicides against black-pod in some of the wetter regions the cocoa farmer can increase his harvest by as much as eight-fold. Considering the price paid to the farmer, £7 10s./cwt. in some parts, the strength of the incentive is obvious. Similarly the benefits of spraying against Mirids are sufficiently striking to appeal strongly to the farmer. In some of the cocoa grown on marginal soils, however, the yield is poor under the best circumstances and can hardly pay for treatment.

Other crops such as maize and guinea-corn are heavily attacked by the stem borers *Busseola*, *Coniesta*, *Sesamia* and *Eldana* which at times cause considerable loss, especially in maize where it can amount to 30 per cent. in quite moderate attacks. In cultivated sorghums the midge *Contarinia sorghicola* (Coq.) causes losses which Harris in Northern Nigeria estimates at nearly £2m. in some years.

Although the total production of these crops is great the loss through insect attack is spread out over many farmers so that no-one feels it very keenly. Hence they tend to accept it as part of the order of things, rather than apply remedial measures. Even such simple precautions as disposing of crop residues containing the pests in diapause are neglected.

Another important food crop—the yam (*Dioscorea*)—is severely attacked by Dynastid beetles. The total value of tubers damaged and destroyed is very considerable but here again it does not fall very heavily on any individual and it is doubtful if control measures now being worked out will ever be generally adopted by the peasant farmer community.

In the case of cotton in Northern Nigeria much of the crop consists of stunted bushes grown under poor cultural conditions. Here it is a waste of money applying chemical control methods. The emphasis must go on better cultural methods. Pest control methods are known but the level of farming is too primitive to benefit from them. Plant protection must await the arrival of better agriculture.

It is interesting to see how research and extension in plant protection are doing in new political systems such as the Federation of Nigeria. It was originally intended that research should be centred in the Federal research departments and extension in the regional ministries but that is not the way it is working out in practice. Each of the regions has set up its own research organisation to deal with local problems. This has gone furthest in the Northern Region where a large research station has been in operation for some years. These organisations have the advantages of compactness and local priorities. But they are closely integrated with the ministries and tend in consequence to lack proper scientific direction. Considerable rivalry has sprung up and there exists a decided danger of duplication and waste of effort unless a better understanding is reached. But whoever does the research there should be no difficulty in bringing the results home to the farmers through the regional extension services. As far as the control of pests and diseases is concerned this is being very successfully carried out in most of the cocoa growing districts. And there is little doubt that it could and would be done in other areas if the economics of the crops made it worthwhile. But the trouble with many West African crops is that they are too low priced to be worth spraying.

It may be of some interest to speculate about the future of agricultural development in general and on plant protection in particular. It is of course impossible to predict what is likely to happen, especially in Africa where conditions are changing so rapidly, but there are general principles which indicate the probable course of events. Modern requirements would seem to dictate a movement away from peasant farming towards some form of capitalised agriculture. What form is it likely to take? Local development corporations have a poor record. There have been several expensive failures. But they could possibly do better under present conditions. Land Settlement Schemes have been more successful on a small scale. Their present large scale development still has to face the test. In Western Nigeria they represent a bold scheme for turning some of the 100,000 school leavers a year into modern enlightened farmers. Company plantations hold out the best prospects but they are political anathema. They may be more acceptable in modern trappings with a strong local flavour in titular styling and directoral constitution. Such adaptations have, in fact, been welcome in other spheres. The keenly felt need for foreign investment may also help to overcome political repugnance at the idea of capitalised plantations. The establishment of this form of agriculture would greatly facilitate the application of extension methods and bring home their advantages to farmers in the neighbourhood.

An interesting development is the company assisted venture. This is seen at its best in some tobacco production areas where the crop is cultivated by small co-operatives of some fifty or sixty farmers with the assistance and guidance of the tobacco companies. The latter clear and prepare the land, supply seedlings, buy the leaf and either do the curing, in the case of flue-cured leaf, or make loans and technical assistance available for the construction of curing barns. The farmers are responsible for cultivation and pinning. The companies maintain considerable quantities of agricultural machinery including sprayers and dusters as well as stocks of chemicals. Plant protection operations are carried out by the farmers under the supervision of the company, and here again the influence exerted on individual peasant farmers must be very considerable.

One of the big problems which plant protection in West Africa will have to face is that of maintaining equipment. In this climate machinery deteriorates with astonishing rapidity. Repair facilities are practically non-existent and few suppliers ever dream of stocking spare parts. The reason is not far to seek. The profit lies in selling machines not in supplying spares. This is a source of continual irritation and annoyance and severely discourages farmers from investing in sprayers and dusters. What seems to be needed is some sort of Government agency to import and supply plant protection machinery and spares to farmers. In this connection it should be noted that there is great need to standardise equipment and specialise in a few suitable models.

The present policy of some West African Governments of granting loans to approved farmers for the purchase of machinery and chemicals for plant protection purposes and of subsidising these products will undoubtedly have a profound effect on the future of plant production work, at least in the cocoa producing regions. These services are, of course, dependent on the high level of world commodity prices. There may be set-backs in the future but West African agriculture has seen the light and is not likely to retreat back into the darkness of ages.

Discussion

Dr. K. Mellanby pointed out that research work could only be applied when it produced results that were worth applying. There was a danger that over-organisation would not produce such results and that active scientists would be turned into sterile (but highly paid) administrators. In research, he said, a reasonable state of anarchy might be the most productive. Committees and councils were able to encourage and support research, but they could not initiate or administer it. The ideas had to come from the research worker himself, for which freedom to express himself was required, and the scientist who asked for direction was not a type suitable for research. The virtue of bodies like the Agricultural Research Council was that they were usually prepared to listen to the active worker, and often to support him.

Mr. G. G. Samuel said that in Britain, at any rate, the position was not as bad as Dr. Mellanby had pictured. Research was at a high level, as was obvious from the large numbers of oversea visitors who came to consult with workers in this country. He said that he had lived under three systems: in Australia, where the Department of Agriculture controlled the research; in England, where before the War the Advisory Service was attached to the universities; and where later, during the War, it became independent. An advisory service linked with independent research, he thought, was capable of providing the best results, if the links between the two were fully used. Independent research in the United Kingdom originated in the Ministry of Health during the First World War, when doctors did not relish the idea of becoming Civil Servants and the result was the organised independence of the Medical Research Council. About ten years later, the Agricultural Research Council was formed on a similar basis, under the Privy Council, and it had tried to co-ordinate as little as possible.

The Chairman drew the discussion to a close by remarking that the speakers had raised so many points that profitable discussion could have been carried on for several days, but time was limited, even for his closing address. He had expected to hear of many diverse experiences in different parts of the world, but instead he had been impressed by the similarity of people's experiences and by the obvious signs of enthusiasm in areas where growers were concerned with profitable cash crops.

APPENDIX V

REVIEWS OF WORK IN ECONOMIC ENTOMOLOGY IN THE COMMONWEALTH, 1954-1959

CONTENTS

PAGE

Aden ... 198

Australia ... 202

Barbados ... 211

British Guiana ... 214

British Solomon Islands ... 216

Canada ... 219

Ceylon

Tea Research Institute ... 242

East African High Commission

East African Agricultural and Forestry Research Organisation (*Forest Entomology*) 244
East African Trypanosomiasis Research Organisation ... 246
East African Veterinary Research Organisation ... 253

Federation of Malaya

Department of Agriculture ... 255
Forest Research Institute ... 256
Rubber Research Institute ... 258
Institute for Medical Research ... 259

Federation of Nigeria

Federal Ministry of Economic Development ... 261
Federal Ministry of Health (*Malaria Service*) ... 265

Federation of Rhodesia and Nyasaland

Ministry of Agriculture ... 267
Cotton Pest Research Scheme ... 271
Tobacco Research Board ... 274

Fiji ... 276

Ghana

Ministry of Agriculture ... 279
Cocoa Marketing Board ... 282

Great Britain ... 285

Jamaica ... 296

Kenya

Department of Agriculture ... 298
Forestry Department ... 303
Department of Veterinary Services ... 304

Mauritius ... 310

New Zealand ... 313

PAGE

Northern Nigeria
Ministry of Agriculture 325
Ministry of Animal Health and Forestry 328
Ministry of Health 331

Northern Rhodesia
Department of Veterinary Services and Tsetse Control 335

Nyasaland 341

Seychelles 343

Southern Rhodesia
Department of Tsetse and Trypanosomiasis Control and Reclamation 345

Tanganyika 347

Trinidad
Department of Agriculture 350
Commonwealth Institute of Biological Control 351

Uganda 353

Union of South Africa 361

West Africa
West African Cocoa Research Institute (Ghana) 385
West African Cocoa Research Institute (Nigeria) 386
West African Institute for Trypanosomiasis Research 391
West African Stored Products Research Unit 394

West Indies
Regional Research Centre 397

Zanzibar 399

ADEN

REVIEW OF WORK IN ECONOMIC ENTOMOLOGY

By J. H. Proctor

Empire Cotton Growing Corporation, Aden

Organisation and Staffing

Entomological work in Aden is carried out by the Research Section of the Department of Agriculture, Aden Protectorate. The Section is accommodated on a Research Station at El Kod, in the Abyan cotton-growing area, and is financed by Colonial Development and Welfare funds, the Empire Cotton Growing Corporation and contributions from the cotton producing States. The terms of reference of the C.D. & W. scheme are to conduct, principally, investigations on cotton and the research officers, including one entomologist, are provided by the Empire Cotton Growing Corporation. The Research Section was originally set up in association with the Abyan Board, the irrigation and marketing authority, but in 1956 it was finally integrated with the Department of Agriculture.

Locust control is the responsibility of the Department of Agriculture, which works in co-operation with the local protectorate states. Medical entomology, principally the control of malaria vectors, is carried out by the Protectorate Health Service. Entomological research in Aden may be said to have started in 1955, when the first entomologist was appointed to the Research Section.

FIELD CROPS

Cotton

The only cash crop of any importance in the Protectorate is long-staple cotton of a Sudan-Egyptian type. This is grown, principally, in two alluvial fan deltas, those of the Wadi Bana in Abyan and the Wadi Tiban in Lahej. Cotton has become of great importance to the economy of the Protectorates since the introduction of annual types in 1946. These replaced an earlier, probably very ancient, cultivation of Asiatic types (probably *Gossypium herbaceum*, still extant in the Emirate of Beihan) and *G. hirsutum* race *punctatum*. Cotton is grown as a winter crop on a single pre-sowing irrigation, and is sown in August and September.

Entomological work is concentrated on cotton. The pest complex in Aden is largely of species occurring on cotton in the arid parts of Africa, and indeed the fauna of south western Arabia includes very many Ethiopian species. This is no doubt the result of the relatively recent separation of south western Arabia from the African continent.

Of leaf insects only *Aphis gossypii* Glov. is of any importance. Occurring also on *Hibiscus esculentus*, *Solanum melongena* and water melon, it tends to be important only on well grown cotton which has a dense leaf canopy. Sooty mould is produced and there is some indication of a drop in lint strength. *Cheilomenes propinqua* (Muls.), *Xanthogramma aegyptium* (Wied.) and Chrysopidae are important predators. *Aphis* can be controlled by Rogor 40 at 20 fluid ounces in 100 gal. of water per acre.

Two species of *Empoasca*, neither of great importance, occur—*Empoasca lybica* (de Berg.) and *E. flavescens* (F.). Hopper burn is seen only in poorly grown cotton and in well grown cotton too widely spaced with incomplete ground cover. The main alternative hosts are *Solanum melongena* and *S. dubium*. *Empoasca* can be controlled by Rogor 40 at 10 fluid ounces in 100 gal. water per acre. In the absence of effective rainfall, *S. dubium* appears after irrigation of the cotton land and does not dry out until the cotton is well grown. There is therefore no mass migration of Jassids from this host to young cotton and no sudden increase in jassid numbers at a critical stage of growth.

Minor pests include *Bemisia tabaci* (Gennadius), *Podagrica puncticollis* Weise (which appears to prefer *Abutilon muticum* to cotton), *Sphenoptera gossypii* Cotes, *Oxycarenus hyalinipennis* (Costa), *Creontiades pallidus* (Ramb.), *Spodoptera exigua* (Hb.), *Prodenia litura* (F.) and *Xanthodes graellsii* (Feisth.).

Of bollworms, only *Diparopsis watersi* (Roths.) is important in Abyan and Lahej, although *Earias insulana* (Boisd.), *Pectinophora gossypiella* (Saund.) and *Heliothis armigera* (Hb.) also occur. *E. insulana* occurs mainly in *A. muticum*, which after sparse growth over the summer springs into rapid growth when the land is watered. It thus has one main flush of growth during the year, coinciding with the cotton season. *Earias* shows no tendency to move from *Abutilon* to cotton and is rarely found in the Abyan crop although the *Abutilon* is uniformly infested. Thus with *Earias*, as with *Empoasca*, the relative unimportance of the species may be a result of the lack of effective rainfall causing the growth period of the alternative hosts to coincide with rather than precede that of the cotton crop.

At Meifa Hajr, a cotton producing area of the East Aden Protectorate, a high water table maintained by the perennial flow of the Wadi Hajr permits unpulled cotton plants to continue to grow over the dead season and permits steady flowering throughout the year of *Cienfuegosia* sp. near *welshii*, a host of *Earias*. Under these conditions, *Earias* is of some importance to the crop.

Pectinophora gossypiella has occurred in Abyan and Lahej but has not been found since 1958. It has regularly occurred in the high water table area of Meifa Hajr, the infestation being maintained in surviving perennial cotton types (*Gossypium barbadense* race *brasiliense*) and most probably in unpulled plants over the dead season. Pulling out of cotton plants for the close season is good in Lahej and while increasingly lax in Abyan much of the unpulled cotton remaining fails in the summer through water shortage. There is some indication that few diapause pupae are produced in the Abyan crop season, but further work is needed.

Heliothis armigera occurs in small local foci in the early stages of the crop. It causes complete shedding of the first formed buds, but where growing conditions are good the plants recover and there is little loss of crop although some delay. Alternate hosts of importance are *Dolichos lablab*, *Hibiscus esculentus*, maize, tomato, ground-nuts, pigeon pea and (possibly) sorghum. At El Kod *Heliothis* has appeared first on *Dolichos* and ground-nuts, thence moving into cotton and persisting last on pigeon pea. Numbers decline towards the end of the year and it is very rare in the later stage of the crop. Its absence over the summer on the few hosts available in gardens strongly suggests that long cycle pupae are formed. Endrin 0·125 per cent. emulsion at high volume gives good control on cotton. *Heliothis* is heavily parasitised by the Calliphorid, *Goniophthalmus simonyi* Villen., particularly on ground-nut, *Dolichos* and cotton.

Diparopsis watersi occurs throughout Abyan and Lahej but is not found in the East Aden Protectorate. It is the most important insect pest in the Aden Protectorate.

Diparopsis appears on the first buds to be formed in September in early budding American types on the Research Station and in *punctatum* hybrids in the commercial crop. The initially low population increases until at the end of January some five per cent. of the bolls may be damaged. The proportion of damaged bolls normally comes to exceed five per cent. only later, when much of the crop has opened, so that loss by damage of the bolls is not normally large. Shedding of buds and young bolls is caused from November onwards, but the percentage of damaged sheds recovered indicates *Diparopsis* to be an important cause of shedding, in relation to natural shedding, only from January onwards. Total shedding is then less and many of the fruiting bodies shed could not mature before the end of the crop. The larger part of the total bud shedding occurs in December during the development of the young bolls and is physiological in origin while boll shedding occurs mainly in January. Loss of crop by shedding and direct damage to the bolls is therefore normally small. This has been confirmed by spraying trials in which under normal conditions protection of the crop with endrin has not reduced the final degree of shedding to any extent.

Investigations into the diapause mechanism indicate that more long cycle pupae are formed towards the end of the season. Emergence from long cycle pupae does not take place during the summer when soil temperatures are high. Emergence takes place over the two months or so following watering which, besides a possible direct effect on the pupae, reduces soil temperature. As cotton does not start budding until some three months after watering the larger part of the moth flight is spent before buds are available. There is some indication that emergences from unwatered land may take place on watering the land in the following year, after a diapause of eighteen months. When land is not watered, however, the main bulk of the emergence takes place from November to January when soil temperatures drop during the winter.

The relation of the moth flight to the cotton crop is undoubtedly the most important natural agency controlling *Diparopsis*. Parasitism is negligible, only one species, *Drino* (*Prosturmia*) *inconspicua* Mg. having been found, and causing only a low degree of parasitism, apparently in the first stages of the crop.

There is no deliberate rotation of a dry fallow in Abyan or Lahej but annual variations in the volume of irrigation water available result in fluctuations in the area watered. When land cropped with cotton the previous season is left unwatered, moths emerging in November to January are intercepted by cotton on neighbouring land in a suitable stage for breeding and a high population is built up. Cotton surrounded by or fringing unwatered land is therefore heavily attacked at a critical stage of crop formation, and heavy losses can result. Conversely, when a year of poor flood is followed by one of good water supply, a large area of cotton is available to absorb any small moth flight emerging from diapause pupae eighteen months old and the crop occupying land unwatered the previous year is very lightly attacked. Thus the degree of infestation by *Diparopsis* changes with variations in the availability of water.

The enforcement of a close season for cotton in Abyan has grown increasingly lax. Pulling out is delayed, and inevitably a certain amount of cotton remains when watering takes place. Although water strain normally limits growth over the dead season some leaves remain, and such cotton rapidly comes into bud on watering; the interception of the moth flight by it is certainly the main cause of severe local infestations of *Diparopsis*.

Insecticides are neither used nor, normally, required in the commercial crop. Their use in research has been to assess the importance of *Diparopsis* by evaluating the yield response to protection against attack. Endrin 0·125 per cent. emulsion sprayed weekly at high volume keeps plants virtually free from *Diparopsis*. Such trials have shown the small loss normally due to *Diparopsis* (the importance of other species controlled by the spray being negligible), and the degree of loss that can be caused by emergence from unwatered land at a critical stage of crop formation and by infestation from early-sown cotton that has intercepted the moth flight.

The general recommendations for the control of *Diparopsis* are therefore that a strict close season be enforced and that no cotton be sown on early floods. This eliminates the possibility of the moth flight being intercepted by cotton suitable for breeding unless moths emerging from late watered land are intercepted by cotton sown at the start of the sowing period. The possibilities of eliminating the chances of such an interception by compressing the sowing and watering periods still further are limited by the availability of water, the irregularity of the supply and the capability of the irrigation system. As far as water resources permit it is important to secure the early watering of land cropped with cotton the previous year, and a dry fallow should never follow cotton in any rotation that may be introduced.

OTHER CROPS

Work on other crops of lower cash value has been largely limited to the identification of species. The following list of the principal crop pests may be of some interest as there is little literature on the economically important insects of the Aden Protectorates.

Sorghum	*Sesamia cretica* (Led.), *Contarina sorghicola* (Coq.), *Aphis* (*longiunguis*) *sacchari* Zehnt.
Maize	*Heliothis armigera, S. cretica, Aphis* (*Rhopalosiphum*) *maidis* Fitch.
Wheat	sp. of Aphidae, *Agrotis spinifera* (Hb.).
Sesamum	*Antigastra catalaunalis* (Dup.), *Asphondylia sesami* Felt, *Nezara viridula* (L.)
Dolichos	*Bemisia tabaci, H. armigera, Prodenia litura, Acanthomia* sp.
Groundnut	*H. armigera, Xanthodes graellsii.*
Dates	*Batrachedra amydraula* Meyr., *Carpophilus* spp., *Oryctes monoceros* (Ol.).

Citrus	*Aonidiella aurantii* (Mask.), *Aleurocanthus woglumi* Ashby.
Other fruits	*Pardalaspis quinaria* Bez., *A. woglumi.*
Cucurbits	*Aphis gossypii*, *Dacus ciliatus brevistylus* Bez., *Epilachna chrysomelina* (F.), *Asbecesta transversa* All., *Aspongopus* sp.
Eggplant	*Urentius* sp., *Empoasca lybica*, *E. flavescens.*
Hibiscus esculentus	*Podagrica puncticollis*, *Oxycarenus hyalinipennis*, *Pectinophora gossypiella*, *Heliothis armigera*, *Earias insulana*, *Aphis gossypii.*
Cabbage	*Brevicoryne brassicae* (L.), *Plutella maculipennis* (Curt.), *Hellula* sp.
Tomato	*Heliothis armigera*, *Prodenia litura.*

LOCUSTS

In the Aden Protectorate the Desert Locust, *Schistocerca gregaria* (Forsk.) breeds on watered land in flood irrigated areas and the wadi beds, and in vegetation springing up on unwatered land after rain. Solitary breeding occurs on a considerable scale in Abyan, particularly in *Tribulus pterocarpus* and *Dipterygium glaucum.* In initially solitary populations in *Tribulus*, population increase is accompanied by the development of colouration and behaviour characteristic of the gregarious phase. Irrigation of areas where cultivation is habitually poor results in an increase in the amount of *Tribulus* and thereby favours solitary breeding and at least a partial gregarisation.

Information on breeding and swarm movements is gathered by the Department of Agriculture, and bait is distributed to farmers in co-operation with local state authorities.

MEDICAL

Anopheles gambiae Giles is the principal malarial vector on the coast and the lower hills, but *Anopheles sergenti* (Theo.) may be more important in the mountains, high plateaux and northern desert areas. Mosquito control is by routine house spraying with dispersible BHC at intervals of three to four months. The most important insect affecting health, however, remains the house fly, which is fostered by the primitive sanitary arrangements universal in the Protectorates.[1]

Reference

[1] Annual Report of Aden Protectorate Health Service for the year 1957. Aden.

AUSTRALIA

1. REVIEW OF ENTOMOLOGICAL RESEARCH IN AUSTRALIA

Detailed reports of work in progress in Australia were submitted to the 1948 and 1954 Conferences and the latter was included in the published report of the Conference. All of the institutions and organizations mentioned in the latter report are still actively engaged in research and most of the problems previously mentioned are still being investigated. The present summary will, therefore, deal only with significant new developments and reference should be made to the earlier reports for background. In the 1954 review it was stated that there had been a growing conviction in Australia that research on the physiology and ecology of insects and factors influencing their populations should receive increasing attention. During the past six years, more emphasis has been placed on ecology and population dynamics in the Division of Entomology of C.S.I.R.O. at Canberra, the Waite Agricultural Research Institute in Adelaide and the Tasmanian Department of Agriculture.

Amongst the more recent developments the following are worth particular mention. The Queensland fruit fly, which is one of the most serious horticultural pests in Australia, has been the subject of greatly intensified ecological work and large numbers of opiine parasites have been introduced from Hawaii. Some field recoveries have been made, although it is too early yet to say whether beneficial results will follow. There has been a marked increase in the research programme on the cattle tick, *Boophilus microplus* (Can.), both in Queensland and in New South Wales and greatly improved methods for reducing losses are now available. Another notable development in Australian entomology has been the demonstration that it is possible to eradicate the Argentine ant from the main areas in which it has become established, namely Sydney and Perth. Eradication from many suburbs in Sydney has already been achieved. An increasing number of insects have developed resistance to insecticides. The cattle tick is resistant to several individual acaricides that can no longer be used in some localities. Perhaps most important of all has been the spectacular development of resistance by the sheep blowfly, *Lucilia cuprina* (Wied.), to dieldrin which earlier gave good control of this insect.

Since the 1954 review there has been a general, small increase in the amount of work being done and the number of entomologists engaged in research. The most notable increases in the scientific staff and facilities have occurred in the Department of Entomology, Waite Agricultural Research Institute, University of Adelaide, where a new building, completed in 1959, includes much improved facilities for chemical, physiological and ecological work; in the Division of Entomology, C.S.I.R.O. Canberra, where an administrative block with constant temperature rooms, and some new insectaries and glass-houses provide greatly improved facilities; and in the New South Wales Department of Agriculture where the Entomological Branch has moved to new premises at Rydalmere.

Agricultural Pests

In all of the State Departments of Agriculture field tests have been carried out with new insecticides against many agricultural pests.

The taxonomy of *Heliothis* and *Agrotis* and some of the Aphids has been studied.

Some research has been done in the Northern Territory on the control of rice pests, and a taxonomic revision of the Schoenobiinae (rice stem borers) has been completed.

Insects of Pastures and Field Crops

Australia is passing through an era of intensive pasture improvement and management stimulated by the spectacular returns from it and the fact that the pastoral industries are still of major importance in the Australian economy. In many instances, insect problems have arisen as a direct result of pasture improvement. In others, the increased attention being paid to pastures has brought to light problems which already existed but had not been fully recognized in the past.

The following are some of the pasture insects on which work is being carried out:

Aphodius howitti Hope and *Aphodius tasmaniae* Hope

The Victorian Department of Agriculture reports that *A. howitti* is now being well controlled by the use of lindane incorporated in superphosphate fertilizer mixture. This treatment has been generally adopted throughout the main pastoral areas in Victoria. BHC is also the favoured insecticide for control of *Aphodius* in New South Wales and Tasmania.

Oncopera spp.

Recently there has been a vast increase in the incidence of underground grass caterpillars, *Oncopera* spp., in the north-west of Tasmania and severe damage occurred to pastures that were not treated with DDT. This is the first record of a major outbreak of this species which is normally a minor pest in scattered localities. Increase in numbers is attributed to a succession of wet summers, allowing greater survival of the eggs and young larvae. An extremely severe outbreak of *Oncopera intricata* Wlk. occurred in Tasmania in the late winter and spring of 1957. Detailed ecological experiments on the survival in the field of this major pest species are in progress. Results so far obtained indicate that dense oviposition has a deleterious effect on survival of the larvae and that the amount of pasture cover has an important influence on the survival of eggs and larvae. Ecological studies of *Oncopera fasciculata* (Wlk.) in South Australia are being carried out by the Waite Agricultural Research Institute.

Persectania ewingii (Westw.)

Three outbreaks of the southern armyworm have occurred in Tasmania since 1954. Light traps operated in various areas of the State have shown that the size of the moth flights in spring is a reliable guide to the likelihood of the occurrence of plagues in the late spring and summer. Some work on this pest is also being done in Victoria.

Othnonius batesi Olliff.

This native insect has caused spectacular damage in northern New South Wales. It was not recognized as a serious problem until about 1957 and since then the known area of distribution has expanded considerably. The New South Wales Department of Agriculture is studying the ecology and control of this insect. Chemical control is difficult because the insect spends most of its life at such depth in the soil that ordinary insecticide treatments are not effective.

Amnemus quadrituberculatus (Boh.)

This weevil has recently presented a new problem in New South Wales. On the north coast of the State attempts have been made to develop improved pastures with subterranean clover. The weevil appears to have been a major factor in preventing their establishment. Co-operative studies on its ecology and control are being done by the New South Wales Department of Agriculture and the University of Sydney. Some success has been obtained in trials with dieldrin, aldrin and chlordane, although the major problem of field control remains unresolved.

Halotydeus destructor (Tucker) and *Sminthurus viridis* (L.)

Work has continued on these pests in Western Australia, South Australia, Victoria and New South Wales. In Western Australia one application of a combined spray of 1 oz. DDT and 1 oz. malathion per acre gives reasonable control but fails to prevent a build-up of lucerne flea late in the season. In Victoria, 2 oz. lindane per acre is used to control the lucerne flea. In New South Wales, tests have been conducted with some of the organophosphorus insecticides and Gusathion has been found to give some control of both species.

Heteronychus sancta-helenae Blanch.

Co-operative work on the black beetle was begun several years ago by the Division of Entomology, C.S.I.R.O., and the New South Wales Department of Agriculture, the former to study the ecology and the latter direct control measures. The beetle populations declined rapidly soon after these investigations began and accordingly, little progress has been made.

The beetle has been controlled in the south coast districts of New South Wales by the use of lindane applied with superphosphate in combination with summer crop sowings. The Division of Entomology is now testing nematodes (*Neoaplectana* sp.) in Canberra which will be liberated in the field if it is found that they show promise of attacking black beetle larvae. It is also hoped that these nematodes may be of value against *Othnonius* in inland areas.

Pantomorus leucoloma (Boh.)

The white fringed weevil is being reported more widely in New South Wales, lucerne being the main crop concerned. Probably as a direct result of increased establishment of legumes in pastures, this insect is now rated amongst the most serious insect pests in New South Wales. Tests have shown aldrin and dieldrin to be promising against this weevil.

Locusts and Grasshoppers

Investigations on *Chortoicetes terminifera* (Wlk.) have turned to an examination of the practicability of the strategy of outbreak suppression, *i.e.* of early intensive insecticidal treatment in the outbreak areas. To facilitate the location of outbreak centres, a detailed soil and vegetation survey has been undertaken in the Bogan-Macquarie outbreak area. Measures designed to give early warning of a dangerously increasing population level have also been instituted. These include a programme of regular assessments of locust density in selected outbreak centres throughout the outbreak area. Work on aerial spraying of flying swarms has suggested that advantage can be taken (a) of the known dominant flight directions and (b) of the tendency of swarms to be deflected by timber barriers and to cross them at gaps. Experiments on control by manipulating the ecological characteristics of the outbreak-area are being continued.

Factors regulating the abundance levels of several species of grasshoppers that damage pastures in south-eastern Australia have been studied. It has been found that structural features of the pasture are of special significance, and that these are produced largely as a result of overgrazing and can be eliminated by establishing a vigorous, continuous sward of superior, sown species.

Acheta commodus (Wlk.)

Ecological studies of the field cricket are being carried out at the Waite Institute in South Australia and similar investigations, mainly on diapause in the eggs, are in progress in Victoria.

Etiella behrii (Zell.)

This species has appeared as a pest of lucerne in South Australia and investigations are being carried out on its ecology by the Waite Institute.

Adoryphorus couloni (Burm.)

Ecological studies on the red-headed pasture cockchafer are being carried out in South Australia while, in Victoria, field and laboratory investigations on its control are in progress.

Horticultural Pests

Strumeta tryoni (Frogg.)

Increased attention has been given to the Queensland fruit fly. An officer of the Queensland Department of Agriculture surveyed work on fruit flies in Hawaii and California and ecological studies in Queensland have been intensified. The Division of Entomology, C.S.I.R.O., and the University of Sydney have in progress an extensive programme of ecological research on *S. tryoni*. This includes studies on geographic strains of the insect particularly those which may be more adapted to southern Australia, and on aspects of its ecology which are of importance in carrying out eradication campaigns when these become necessary in fruit-growing areas such as the Murrumbidgee Irrigation Area of N.S.W. and parts of Victoria and South Australia. The possibility of overwintering in these areas is also being studied.

Infestations of fruit fly have continued to appear both in Melbourne and in Adelaide but the governments concerned have pursued vigorous eradication campaigns on each occasion. In New South Wales tests have been carried out with insecticides and on the development of male lures. Parahydroxy benzyl acetone and some similar compounds have been shown to have considerable value as a male attractant. Tests with Rogor have shown that complete cover sprays with this insecticide both four and three weeks before ripening of soft fruits, and eight and seven weeks before harvest of apples and citrus should provide satisfactory control. Investigations are also in progress in New South Wales with the object of devising an effective fumigation of infested fruit for export. Ethylene dibromide is very promising for this purpose.

An officer of the Division of Entomology, C.S.I.R.O., spent two years in Hawaii collecting and culturing parasites of the Oriental fruit fly for direct liberation in Australia against the Queensland fruit fly. Approximately 500,000 active adult parasites were liberated in Australia. Fruit sampling in the field is being carried out to investigate the establishment of these parasites. Parasites have been recovered from several localities eight to eleven months after release.

Ceratitis capitata (Wied.)

The Mediterranean fruit fly is restricted to Western Australia except for occasional introductions into South Australia which have been eradicated. Malathion-yeast has proved very effective as a bait and is supplanting older treatments. Dipterex is being extensively used as a cover spray and Rogor 40 and Lebaycid are showing considerable promise. Ethylene dibromide treatment of infested fruit has given satisfactory kills of eggs and maggots in tests.

Cydia pomonella (L.)

The codling moth remains one of the most important horticultural pests in South Australia, Victoria, Tasmania and New South Wales. DDT-resistance has been observed in Victoria and in South Australia. A survey has been done in Victoria to determine the level of DDT-resistance and its extent in the State, and a wide range of new insecticides has been screened. Guthion and Sevin are now giving excellent control of DDT-resistant codling moth populations. Resistance of codling moth to DDT has also been observed in Tasmania, where research has been concentrated on ecological studies with the ultimate aim of modifying the spray schedule to enable full use to be made of natural controlling factors. Similar research on the ecology of the codling moth has been in progress at the Division of Entomology, C.S.I.R.O. since 1957. In South Australia aspects of its ecology and insecticide resistance are being investigated at the Waite Institute. This insect is not permanently established in Western Australia; a new infestation occurred in 1956 and, as before, eradication measures appear to have been effective.

Tortrix postvittana (Wlk.)

Fairly widespread resistance to TDE has appeared in the light brown apple moth in Tasmania. Ecological studies are being carried out on this species both in Tasmania and Victoria and insecticide tests are in progress in Victoria and Queensland.

Aonidiella aurantii (Mask.)

Particular attention has been paid to red scale in Victoria. Fumigation with hydrocyanic acid gas has been replaced by spraying using either a phosphorus insecticide, light-medium grade oil emulsion or mixtures of these containing about half the standard recommended strength of each. Malathion is most widely used. Guthion and Rogor are effective against red scale and are most useful when the soft scales also are present.

There has been an increase in the population of the longtailed mealy bug since fumigation ceased.

An introduced parasitic wasp, *Comperiella bifasciata* How. was established in 1949–50 and is giving excellent control of red scale on an increasing proportion of the citrus acreage. The ecology of red scale is being studied by the Waite Institute on irrigated citrus.

Quadraspidiotus perniciosus (Comst.)

In view of rigorous quarantine restrictions in Europe, control investigations for San Jose Scale have been intensified and various new insecticides have been tried against the pest. Very satisfactory results were obtained from the use of both winter and summer oils with either parathion and diazinon or Guthion as additives.

Insects of Stored Products

Work on hermetic storage of grain has been continued with investigations into the effects of oxygen depletion and carbon dioxide accumulation on all the commoner Coleoptera that infest grain. Funds have been found for the construction of a silo that will permit of large scale experimental work on this method of grain storage.

Commonwealth-wide export flour standards with respect to insect infestation have been drawn up and adopted. Similar action is required for whole cereals.

In the grain industries, there has been a marked swing to the use of aluminium phosphide tablets for fumigation work. The ease and relative safety of the technique brought about its ready acceptance on a large scale but there has not been a comparable reduction of complaints of infestation by overseas markets due probably to the frequent use of inadequate dosage rates and to the difficulty of detecting incipient infestations.

The control of *Ephestia figulilella* Gregson and *Plodia interpunctella* (Hb.) in dried vine fruits has been greatly improved by the introduction of methyl bromide fumigation and the use of pyrethrum film sprays.

Trials using synergised pyrethrum formulations as grain protectants under commercial conditions are being conducted in New South Wales and the protection of packed, dried, vine fruits by the use of synergised pyrethrum paper wrappers is under trial in Victoria.

Investigations into the problems presented by the field infestation of maize by *Sitophilus oryzae* (L.) are being carried out in Northern New South Wales.

A development of major importance has been the SI-RO-MOTH'D process of moth-proofing woollen textiles using treatment with dieldrin emulsions. This method was developed by the Division of Textile Industry, C.S.I.R.O.

Insects of Forests and Forest Products

During the last five years there has been increased interest in Forest Entomology particularly in the New South Wales Forestry Commission, at the Division of Entomology, C.S.I.R.O., and at the Waite Institute in Adelaide. The Waite Institute has appointed a Forest Entomologist whose most important activity will be a study of insects affecting *Pinus radiata* which is widely planted in that State. An entomologist has also been appointed by the Commonwealth Forestry and Timber Bureau.

Phasmatids

The Phasmatids, *Podacanthus wilkinsoni* Macl. and *Didymuria violescens* (Leach), have continued to defoliate forests in certain parts of New South Wales and their populations have also increased to damaging proportions on the southern highlands of N.S.W. and in the highlands of Victoria. Here, the trees affected are of much greater importance than in areas previously infested and preparations are being made for intensive investigations on the ecology of the two species by the Division of Entomology, C.S.I.R.O., in co-operation with the New South Wales Forestry Commission, the Forests Commission of Victoria and other instrumentalities. In Victoria, because of the importance of this insect in catchment areas, it may be necessary to attempt insecticidal control from the air. Several inconclusive experiments have been carried out in New South Wales on aerial treatment of these insects.

Sirex noctilio F.

At the time of the previous review, *S. noctilio* was present in one small area in the south of Tasmania, but it has now extended half way up the island and undoubtedly will soon cover the whole State. Stringent quarantine measures are being taken to prevent *Sirex* from becoming established on the Australian mainland, either from Tasmania or New Zealand.

Hylotrupes bajulus (L.)

Following the importation of prefabricated timber houses from Europe there have, in recent years, been several records of the occurrence of *H. bajulus* in Brisbane, Sydney and Melbourne. This insect does not appear to be established and eradication measures are in force. Fumigation with methyl bromide at a concentration of 3 lb. per thousand cubic feet of air space at 70° F. for 24 hours has been shown to give 100 per cent. kill of all stages of both *Sirex noctilio* and *H. bajulus* in timber of up to 4 inches in thickness. For the eradication of both these insects large stacks and even buildings can be successfully fumigated under polyvinyl chloride plastic sheeting.

Termites

Termite attack on plastics which are being more and more widely used in Australia for cable sheathings, water pipes and other purposes has caused increasing concern to the manufacturers. As a result, standard laboratory tests of plastics from various parts of the world have been carried out in Canberra. These have been followed by field tests.

Studies have been commenced by the Division of Entomology, C.S.I.R.O., in Canberra to assess the damage caused by termites in forest trees. Some interesting studies have been made which show that termites will spread to many neighbouring trees from an old infested tree. Some of those attacked from this main centre of the colony are still reasonably young trees. The studies include several of the most important termite species in New South Wales and Victorian forests.

Psyllids and other eucalyptus pests

In New South Wales useful ecological work has been carried out on *Diadoxus erythrurus* (White) (Buprestidae), a pest of *Callitris* spp., and on *Spondyliaspis* sp. (Psyllidae) which has caused considerable damage to *Eucalyptus saligna* just north of Sydney. In Canberra, studies are being made on the population dynamics of several Psyllids and similar work is being done on sawflies and leaf-eating beetles with the object of learning more of the factors which are operating to regulate the populations of insects in the forests.

Bark beetles

In Western Australia, the importance of bark beetles in pine forests has been investigated and the efficiency of various insecticides has been tested for the protection of pine logs. If it is necessary for them to remain in the forests, logs can be protected for a period of two months by spraying with a 3 per cent. lindane emulsion.

Preservative treatments

Some advances have been made on the preservative treatment of building timbers and plywood. The Division of Forest Products, C.S.I.R.O., has developed and patented a borofluoride chrome arsenic preservative for the diffusion treatment of green building timber which will not be subject to any severe leaching in service. With this preservative, extremely concentrated solutions can be made permitting treatment of scantling-size timber by momentary dipping followed by block stacking to retard drying until the desired penetration has occurred. This formulation has proved highly effective against *Coptotermes* and *Nasutitermes* species. It is also effective against *Lyctus* without addition of arsenic or chromium. The process, developed in 1949, in which green veneer is dipped momentarily in a borax or boric acid solution and then block stacked for a few hours before drying, is now widely used in Australia for prevention of *Lyctus* attack in plywood. Tests have shown that this simple treatment can be used with other preservatives including metal chrome or metal chrome arsenic types which fix in the wood and are, therefore, suitable for use in waterproof or marine grades of plywood. Further work has been done on the effectiveness of toxic compounds added to the glue and very promising results have been obtained by the addition of arsenic trioxide in liquid phenolic glues.

Insects of Medical Importance

The work in progress consists mainly of taxonomic studies. At the Queensland Institute of Medical Research work has continued on two principal lines: taxonomy of Tabanidae and Simuliidae and taxonomy of Acarina, with particular reference to groups of medical interest. Considerable progress has been made with the reclassification of the Tabanidae. Several groups of Acarina have also been revised, aided in some instances by a study of nymphs. An important assemblage of Australian species has been brought together in the previously monotypic genus *Guntherana*. Further collections of mosquitoes have been made in the field, and two strains of an at present unidentified virus have been isolated from *Culex annulirostris* Skuse. Taxonomic work on the mosquitoes has also been done at the Universities of Queensland, Western Australia, Melbourne and Sydney. The taxonomy of sandflies is being given some attention in the School of Public Health and Tropical Medicine, Sydney.

Some tests in Queensland carried out with the W.H.O. kit with *Culex fatigans* Wied. indicate that this species has developed resistance to BHC which has been used by the Brisbane City Council to control its breeding places.

Insects of Veterinary Importance

Sheep blowflies

The ecology of the species known to attack sheep is being further studied. The species differ widely in their habits and diurnal and seasonal patterns of activity. Evidence has been secured that some species—notably *Chrysomyia rufifacies* (Macq.)—do not overwinter successfully throughout the entire summer range of the adults.

Dieldrin, aldrin and diazinon were found to be very effective in preventing and treating strike. However, after two to four years' use dieldrin- and aldrin-resistance in *Lucilia cuprina* is widespread, and diazinon is the main chemical now employed.

Cattle tick

Extensive studies have been made by the Division of Entomology, C.S.I.R.O., of the biology of the non-parasitic stages of the cattle tick, *Boophilus microplus*, to obtain information for use in pasture spelling (destocking) and strategic dipping régimes. In south Queensland a system of four months' pasture spelling obviated the use of acaricides. In central Queensland three months' destocking of pastures results in effective tick control. Experiments with pasture spelling are in progress in north Queensland.

Strategic dipping has proved effective in south Queensland, where ticks become scarce in late winter. Most of the first spring generation of ticks is destroyed by intensive dipping, and good control is then secured in the summer months.

Studies of cattle dips demonstrated the superiority of supercooled-melt DDT over other formulations. Diazinon mixed with DDT in dipping vats gives excellent tick control. The depletion of the γ isomer of BHC from cattle dipping vats was shown to be due to the chemical action of contaminating cattle dung. Dieldrin, aldrin and BHC injected into cattle showed long-term systemic effects on the cattle tick.

Strains of *B. microplus* now occur in Queensland which are resistant to arsenic, the BHC-dieldrin-toxaphene group of acaricides and, to a limited extent, to DDT. Strains are also known which are resistant to both the BHC group and to DDT. The mechanisms and genetics of acaricide resistance are being studied.

Other ticks

Taxonomic studies have been carried out on the genera *Amblyomma*, *Aponomma* and *Ixodes*. Studies have also been made of the biology of *Ixodes holocyclus* Neum. and *Haemaphysalis bispinosa* Neum.

Lice and itch mite

The oviposition habits of many of the species of lice occurring on domestic animals have been studied. The life history of the itch mite, *Psorergates ovis* (Hering), has been elucidated, and tests have shown that only arsenic and lime sulphur dips control this species.

Household Insect Pests

Iridomyrmex humilis (Mayr.)

The Argentine ant eradication campaign has continued in Sydney, New South Wales with considerable success. The treatment of all areas known to be infested was completed in the summer of 1958–59 but since then other infested areas not previously reported have been discovered. The campaign has clearly demonstrated that it is possible to eradicate this ant from infested areas but it has also highlighted the difficulty of discovering infestations.

In Western Australia, a large-scale control campaign was initiated in 1954. Under the provisions of the Argentine Ant Control Act, the campaign was planned to cover a six-year period with an annual expenditure of £105,000. Approximately 40,000 acres of infestation have been sprayed, of which 35,000 acres have been done in the Perth metropolitan area and the remainder in various country centres. Although complete eradication has not been attempted, this has been achieved in many situations and the nuisance value of the Argentine ant has been entirely removed. Legislation has been provided to ensure future finance to deal with survivors remaining after the completion of the main campaign in 1960.

Biological Control

A full account of biological control in Australia and New Guinea is given in a book by F. Wilson recently published by the Commonwealth Agricultural Bureaux. Therefore it seems unnecessary to condense it in this review.

Insecticides and Insecticide Resistance

Chemicals have continued to provide the only practical methods of controlling the majority of Arthropod pests. Although the older chlorinated hydrocarbons are still used extensively, the range of material available has increased considerably, with the result that chemical control measures are now more specific, economical and efficient.

Resistance to chemicals has developed in at least nine species. In some areas *Boophilus microplus* and *Musca domestica* L. are resistant to one or more of the following: DDT, BHC, chlorinated cyclodiene derivatives. Dieldrin-resistance is widespread in *Lucilia cuprina*. *Culex fatigans*, *Cydia pomonella* and *Pieris rapae* (L.) have developed DDT-resistance. *Tortrix postvittana* is probably resistant to DDT. So far resistance to organo-phosphates has occurred only in the mites *Tetranychus telarius* (L.) and *Panonychus ulmi* (Koch). For all of these resistant strains there are satisfactory alternative means of chemical control.

A survey has been made in New South Wales of the incidence of dieldrin-resistance in *L. cuprina*, and the genetics of this resistance has been studied by the N.S.W. Department of Agriculture. The nature, origin, development, inheritance and biochemistry of resistances in strains of *M. domestica* and *B. microplus* are being investigated by the Division of Entomology, C.S.I.R.O.

2. REVIEW OF ENTOMOLOGICAL RESEARCH IN THE TERRITORY OF PAPUA AND NEW GUINEA

Studies in Biological Control

(a) The predatory snail, *Gonaxis kibweziensis* E. H. Smith, was introduced through Hawaii to New Britain to control the giant African snail, *Achatina fulica* Bowdich. *A. fulica* is an important pest of young cacao and various garden crops. The predacious snail was introduced to the Lowlands Agricultural Experiment Station, Keravat, and first released in the field in that area. It has become established at several sites and further liberations are in progress in other parts of New Britain and New Ireland, to which areas the pest is confined. A consignment of *Gonaxis kibweziensis* was sent to Netherlands New Guinea in 1959.

(b) Large populations of the Coccinellid, *Cryptolaemus affinis* Crutch, were transferred from the coast in the Morobe District to the Wau Valley to control the mealybug, *Planococcus citri* (Risso), which had become a major pest of *Coffea arabica* in this area by 1955. The introduction was highly successful and within a few months *P. citri* had been reduced to the status of a minor pest of coffee and populations have remained at a low level ever since.

(c) The Asiatic rhinoceros beetle, *Oryctes rhinoceros* (L.), is one of the most important coconut pests in the Bismarck Archipelago. Several indigenous Dynastids also attack coconuts. The ectoparasitic scoliid wasp, *Scolia ruficornis* F. was introduced from Zanzibar five years ago. It has become established in the Gazelle Peninsula of New Britain, decreasing dynastid populations to some extent although it cannot be claimed that anything more than partial control has been accomplished.

Chemical Control of Insect Pests

(a) Considerable work has been carried out on the insect pests of cacao (*Theobroma cacao*). The most important pests are certain Mirids of the tribe Bryocorini, three species of the curculionid genus *Pantorhytes* and the recently described Coreid, *Amblypelta theobromae* Brown. The following Mirids of economic importance can be controlled on a commercial scale by dusting or spraying with benzene hexachloride and some other insecticides:—

Parabryocoropsis typicus China & Carv.,
Pseudodoniella pacifica China & Carv. and
Pseudodoniella duni China & Carv. in New Britain,
Pseudodoniella laensis Mill. in the Morobe and Madang District,
Pseudodoniella szentivanyi Mill. and *Helopeltis clavifer* (Wlk.) in the Northern District.

Recent trials suggest that dieldrin may be the best specific insecticide to use against *Amblypelta theobromae*. Work is still going on in an effort to control *Pantorhytes* spp. especially *Pantorhytes plutus* (Oberth.) in New Britain and *Pantorhytes proximus* Faust in the Morobe District.

(b) Although tip wilt had been known on rubber seedlings for some years, it was only in August 1955 that the Coreid, *Amblypelta lutescens papuensis* Brown, was identified as the cause of the damage. As well as *Hevea brasiliensis*, *A. lutescens papuensis* attacks many other cultivated plants, including papaw, cassava, sweet potato, choko and a range of ornamentals. It also causes premature nutfall of coconuts in some areas of Papua. This species is highly susceptible to dieldrin and may be controlled on rubber seedlings with dieldrin sprays.

(c) Satisfactory chemical controls have been evolved for the giant snail *Achatina fulica*. The active principle in the baits is the well known snail specific metaldehyde. It has been found that cardboard rings dipped in a suspension of metaldehyde in a waterproofing agent will last for several months in the field and that briquettes made from metaldehyde, sawdust and cement retain effectiveness for up to one year. The use of these materials makes it practicable to control snails in young cocoa crops.

(d) It has been shown that the indigenous ring borer of coffee, *Meroleptus cinctor* Msl., can be controlled by painting the main stems of coffee trees annually with dieldrin. Prior to control, this was the most serious pest of coffee in the Territory, causing loss of crop above the ringed area and sometimes breaking of the stem.

BARBADOS

REVIEW OF WORK IN ECONOMIC ENTOMOLOGY

The entomological problems of Barbados are concerned almost exclusively with sugar cane, on which the economy of the island is largely dependent, but some work is done on vegetable and garden pests, termites infesting buildings and stored products pests. The Entomology Section is also responsible for Plant Quarantine measures. During the period 1954–1959 the most important pests were the following:—

Cane Moth Borer—*Diatraea saccharalis* (F.)

Moth borer causes an annual loss of sugar between 5,000 and 10,000 tons; cane joint infestation varies between 8 and 23 per cent. Since 1929 the only method of control has been the mass-liberation of the egg parasite *Trichogramma minutum* Ril. Attempts to introduce Tachinid larval parasites have been unsuccessful.

Since its inception the *Trichogramma* campaign has been severely criticised on the grounds that the natural parasite population is very large in comparison with the numbers liberated, that early larval mortality is so great that it obliterates any possible effects of increased parasitism, and that the methods of assessing borer damage over the years have been inaccurate. Since 1958 the *Trichogramma* method has been reinvestigated and the results, a preliminary account of which has already been published (Metcalfe, 1959a), showed little evidence in favour of continuing liberations. Briefly it appeared that the classical host/parasite balance was maintained and that the *Diatraea* potential (the number of eggs hatching per acre) was not reduced by *Trichogramma* liberations. *Diatraea* potential was lower in some colonised fields, but there the natural parasite population (which included *Telenomus alecto* (Crawf.) as well as *Trichogramma*) was very large in comparison with the number liberated.

The resources of the Entomological Section have been transferred therefore from *Trichogramma* to the Tachinid larval parasites that have been so successful in the neighbouring islands. After a few preliminary trials with *Paratheresia claripalpis* (Wulp.) and *Metagonistylum minense* Tns. efforts have been concentrated on *Lixophaga diatraeae* (Tns.). This has been reared and liberated in increasing numbers since June 1958. At first the Commonwealth Institute of Biological Control substation in Trinidad gave considerable assistance with the rearing programme, but this practice has been discontinued. The results of the campaign, although very contradictory, have been encouraging on the whole. While it is possible to liberate mature female flies in an apparently ideal field, and yet obtain no recoveries, in two or three areas *Lixophaga* has maintained itself, albeit at a very low level, for at least ten generations. In one locality, particularly favoured by a succession of young canes, parasitism reached 26 per cent.

In the latter half of 1959 strains of *Lixophaga* were obtained from Cuba, Jamaica and the Dominican Republic. These, together with the original naturalised Antiguan strain, were kept as separate breeding lines, and also crossed in all possible combinations giving ten breeding lines in all. These strains exhibit certain differences in their behaviour, particularly in their response to the presence of *Diatraea* larvae. It is hoped that field selection, acting on the widest possible range of genetic material, will result in the evolution of a strain of *Lixophaga* suited to Barbados conditions.

A start was made to investigate differences in the varietal susceptibility of cane. Egg counts in the field and laboratory did not lead to any conclusions as to the ovipositional preferences of the moths. It was shown that the cane joint infestation was determined partly by the growth type, and that the number of canes per acre, which is a more or less fixed characteristic of each variety, was an important factor. It became clear that joint infestation data were more useful for damage assessment than population studies.

Root Mealybug—*Rhizoecus* sp.

Rhizoecus and its associated ant *Acropyga marshalli* Crawley was first recognised as an important pest of cane in 1952. Its presence at the cane roots was associated with retarded growth, but there was some question as to whether it was a primary pest, or was exploiting the weak condition of the cane. Fennah and Smith (1954) and Fennah (1956), visiting Barbados in 1954 and 1955 respectively, showed that the soil where mealybugs were abundant had a very poor structure, and that consequently the cane was suffering from an unbalanced supply of nutrients, particularly of boron and zinc. These preliminary findings have not been further investigated.

Meanwhile trials with soil insecticides gave some hope of control. An application of 13 lb. γ BHC per acre in about 0·5 ton coral limestone dust was recommended for both ratoon fields and preparation land. Cane yields improved considerably. Increases of 2 tons per acre for plant cane and anything up to 14 tons per acre for ratoons were recorded in the trials. At the same time increasing use was made of thorough cultivation of preparation lands, and this together with a shorter crop cycle (only 2–3 ratoons instead of 3–4) has reduced infestations to such a low level that insecticidal treatments are seldom carried out.

More recent trials using sprays in preference to dusts, have revealed several promising insecticides. Endrin (4 lb. per acre) was outstanding, and has been used on an estate scale for treating heavily infested ratoons. Dieldrin and WL. 1650 gave a less rapid control whilst aldrin and Rogor were ineffective.

Rootborer—*Diaprepes abbreviatus* (L.)

Diaprepes larvae feed on cane roots, and when mature may penetrate into the base of the cane itself. Plant cane yields are little affected but the ratoon yields may be considerably reduced.

Early trials with applications of γ BHC and aldrin dusts were unsuccessful, but later trials with emulsions of both endrin and dieldrin, and then WL. 1650 showed great promise. Dieldrin at 2 lb. per acre has now been recommended for control of root-borer (Metcalfe, 1959b). The insecticide is applied as a spray and adequate penetration is given either by a sharp one inch fall of rain or by harrowing. On one estate dieldrin is introduced into the irrigation lines.

The amount of damage suffered by the ratoons depends on the vigour of the cane, which in turn depends largely on the rainfall. In a dry year the effects of rootborer are more obvious. The variety of cane also plays a part. B.49119 with a very strong root system is far more tolerant of rootborer attack than B.37161 which used to be the standard variety. B.49119 has been recommended for all rootborer areas.

Other Cane Pests

Rats sometimes cause very serious losses and rough estimates of up to 10 tons cane per acre have been given. The varieties B.41211 and B.45151 are particularly preferred. Warfarin was used to the exclusion of all other types of poison, but was only effective when distributed regularly.

Elasmopalpus lignosellus (Zell.) was recorded in Barbados for the first time in November, 1959. It attacked the very young shoots of plant canes, particularly in fields which had not been mulched.

Stored Products Pests

A brief survey was made of food storage and stored products pests. On the whole conditions in the large bonded warehouses were good since turnover was very rapid. In the wholesale stores, however, rodents and insects abounded; the greatest need was straightforward hygiene.

A new macaroni factory which reported continual trouble with infested products was cleared of insects. Incoming flour was fumigated with methyl bromide, and the factory premises sprayed with malathion. After that sales mounted and turnover became so rapid that these measures were no longer necessary.

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BRITISH GUIANA

REVIEW OF WORK IN ECONOMIC ENTOMOLOGY

By C. P. Kennard

Entomologist, Department of Agriculture

During the period 1955–1959, there were three entomologists in the colony. On the staff of the Department of Agriculture is one entomologist whose work is connected with pests of crops including rice, coconuts, citrus, cocoa; Bookers Sugar Estates Ltd., has its own entomologist working on sugar cane pests. There is also an entomologist concerned with investigations on rice storage pests and these investigations are financed by the Government of British Guiana, the B.G. Rice Development Company and the B.G. Rice Marketing Board.

Sugar cane

The damage done by the giant moth borer, *Castnia licoides* Boisd., has increased considerably during the last few years because of the abnormal weather conditions which have rendered flood irrigation impracticable. Aerial spraying with BHC at 1 lb. γ isomer per acre gave some degree of control. Damage by the small moth borer *Diatraea* sp. during the period under review remained fairly constant at about 6 per cent. joint infestation. Endrin and BHC sprays at 0·25 and 0·50 lb. per acre applied at fortnightly and monthly intervals did not give any significant reduction in joint infestation.

Outbreaks of the yellow sugar cane Aphid, *Sipha flava* (Forbes), have occurred within the last two years in sugar cane cultivations in various parts of the country. The variety B47258 has been found to be very susceptible to attacks by this pest. Mist-blowing with malathion at 1 lb. of toxicant per acre and with dimethoate at 0·025 gave excellent control of the pest.

The rat, *Holochilus sciureus berbicensis*, is generally regarded as one of the most destructive pests of sugar cane in the colony. Investigations by G. I. Twigg, Colonial Rodent Liaison Officer, have shown that *Holochilus* exists mainly on a vegetation diet. In savannahs surrounding cultivations, the rat feeds on succulent plants such as wild starch, *Thalia* sp., and bamboo grass, *Hymenachne amplexicaulis*, and in sugar cane, cultivations of young canes are preferred to old ones, and varieties with soft stems to those with hard stems. It has been observed that outbreaks of the rat occur generally after periods of heavy rains when the savannahs are flooded and the rats are forced to seek higher ground. Control measures recommended are baiting around the perimeter to prevent infestation from neighbouring savannahs and rice fields, and baiting within the cultivations to control the rats present.

Rice

Padi bug, *Oebalus poecilus* (Dallas), was investigated by C. R. Wallace, seconded from the Colonial Office Pool of Entomologists during 1952–1954. In his report Wallace has shown that the padi bug is a species, normally occurring on wild grasses, which moves into the rice fields and attacks the crop when the grains are in the " milk " and " dough " stages. Several species of grasses have been found to be host plants of the bug, bamboo grass, *Hymenachne amplexicaulis*, appearing to be the most important. The damage attributed to padi bug is stated to be prevalent in the eastern rice growing areas and this regional prevalence is associated in the report with the prevalance of bamboo grass. Dusting with BHC at 10–30 lb. per acre is recommended as the control measure for this pest.

The main stem-borers of rice are *Diatraea saccharalis* (F.) and *Rupela albinella* (Cram.). They were suspected of causing considerable loss of paddy but investigations carried out between 1955–1957 indicate that the population of *Diatraea* is low, and that the low population is probably due to parasitism by the Amazon fly, *Metagonistylum minense* (Tns.). *Rupela* is common especially on transplanted rice but the numbers fluctuate widely from year to year. One egg parasite, *Telenomus rowani* Gahan, and three ichneumonid larval parasites, *Heterospilus* sp., *Idechthis* sp. and *Polycrytidea flavopictus* (Ashm.) were reared from *R. albinella*.

The rice water weevil, *Lissorhoptrus simplex* Ksl., the larvae of which feed on the roots of the rice plant, has within recent years caused considerable damage to dry sown padi.* The control measure recommended for this pest is that of draining and drying of the land when the larvae are observed. However, because of the lack of proper drainage and irrigation facilities and because of abnormal weather conditions this method of control could not be generally adopted. Control of the larvae by seed treatment with aldrin, dieldrin and lindane is being investigated.

Coconuts

Investigations have shown that the coconut moth borer, *Castnia daedalus* (Cram.), attacks coconuts grown mainly on heavy clay soils; a 1 per cent. dieldrin spray is very effective in controlling it. The dieldrin spray is applied to the centre of the palm with stirrup pumps with the hoses attached to long bamboo lances, and with knapsack sprayers with long extension lances.

The tree nesting ants, *Azteca* sp., which build large carton nests on the trunk of the trees just below the canopy and live in association with the Coccid, *Ischnaspis longirostris* (Sign.), are effectively controlled by spraying the nests with a solution of either 0·3 per cent. aldrin, 0·2 per cent. dieldrin or 0·9 per cent. chlordane.

After a lapse of 40 years, a major outbreak of the locust, *Tropidacris latreillei* Perty, was recorded in 1957. The locust feeds mainly on the weed, *Quassia* sp., which grows amongst coconuts and only attacks coconuts when the weed has been completely destroyed. Aerial spraying with dieldrin was effective in keeping the pest under control.

Leaf cutting ants (*Atta* sp.)

These insects which are amongst the most destructive pests of crops such as coffee, citrus and ground provisions were generally controlled by treating the nests with aldrin and chlordane sprays. Recent experiments have shown that fogging with a mixture of aldrin and dieselene is very effective against this pest. In a campaign carried out in 1959, some 1,000 nests were destroyed by fogging.

Store product pests

Fifteen species of insects have been recorded as affecting padi* and ten as affecting rice in British Guiana. Of these insects, the rice weevil, *Sitophilus oryzae* (L.), is the most important when both padi and rice are considered, with the lesser grain borer, *Rhizopertha dominica* (F.), second, and the paddy moth, *Sitotroga cereallella* (Ol.), third in order. The rust-red flour beetle, *Tribolium castaneum* (Hbst.), and the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.), are secondary in their attacks following those of the previously mentioned insects. Investigations carried out so far have shown that *Sitotroga*, *Calandra* and *Rhizopertha* can infest padi in the fields and before it is brought to the mills.

It is estimated that the monetary loss to the rice industry through storage insects is at least $844,000 (£175,000) per annum.

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* Rice in the husk.

BRITISH SOLOMON ISLANDS

REVIEW OF ENTOMOLOGICAL RESEARCH

There has been no provision for a permanent entomologist in the Department of Agriculture, British Solomon Islands, during the period under review. However, from 1953 until 1958, an entomologist has been working in the Protectorate under a Colonial Development and Welfare Scheme specifically on the problem of immature nutfall of coconuts. A limited amount of work has also been undertaken on other pests of coconuts and also of cacao, a crop relatively new to the Solomons.

Immature nutfall of coconuts

Up to the present, coconuts are the only cash crop grown in the Protectorate, and the production of copra is the mainstay of the economy. Serious losses from immature nutfall have occurred since before the war when the causal organism was found to be the Coreid bug *Amblypelta cocophaga* China. It was early appreciated that the local distribution of nutfall is governed by the distribution of ant species occupying the palms, some species largely preventing *Amblypelta* attack and other species scarcely interfering.

From 1953 to 1956 the nutfall problem was surveyed on a broad basis by Mr. E. S. Brown. It was established that at least four distinct species of *Amblypelta* occur in different parts of the Solomon Islands group, and that they vary greatly in the severity of damage caused. *A. cocophaga* China is by far the most important species. *A. cristabolensis* Brown and *A. costalis* Van Duzee also feed on the coconut palm but do not cause serious damage, whilst *A. gallegonis* Lever probably does not attack coconut at all. Thus some islands in the group are free, or practically free, from nutfall, and one long-term method of dealing with the problem is to encourage more coconut planting in those areas.

A much clearer and more detailed picture of the importance of the various ant species which occur on coconut palms, in determining *Amblypelta* attack, has also been built up. Four main species are involved. *Oecophylla smaragdina* (F.) gives practically complete protection against *Amblypelta* to palms it occupies. *Anoplolepis longipes* (Jerd.) also gives satisfactory control, but not quite as good as *Oecophylla.* The ant species *Pheidole megacephala* (F.) and *Iridomyrmex myrmecodiae* Emery give negligible protection and are antagonistic to the two beneficial species, and when present prevent them occupying the palms. Many other ant species were also recorded from coconut palms from time to time, but do not seem to be important in relation to nutfall.

Attempts have been made to evaluate crop loss from nutfall on the principal islands, but in many cases data on the planted acreage in each plantation and annual production figures over a period of years have been lacking. No actual estimate of present losses has thus been put forward as this would of necessity be based largely on guesswork.

The fact that some ant species provide good protection against *Amblypelta* presents a possible solution to the nutfall problem, if control could be effected over the species of ants present in an area.

It has been determined, by detailed observations extending over several years, that considerable fluctuations may take place in the ant species predominant in a particular area. Investigations were thus undertaken to determine if possible the reasons for these changes. The correlation considered most likely was between ant species and type of vegetation occurring in a particular area. Detailed observations have failed, however, to show any correlation between dominant ant species and vegetation type, with the possible exception of *Iridomyrmex* which is often associated with epiphytes and heavy creeper growth on the palm trunks and undergrowth.

Often, when changes in ant species were taking place, physical conflict between different species was observed but sometimes one ant species retreated before another took over.

The changes, which certainly take place, in the ant populations of the palms are thus probably due to certain intrinsic factors, at present unknown, rather than to vegetation changes. Until these have been investigated and clarified, there is little prospect of controlling nutfall permanently by this method.

Attention was thus turned in 1956 to the possibility of controlling *Amblypelta* directly by insecticides. During the period 1956–1958, Mr. P. G. Fenemore succeeded Mr. E. S. Brown as entomologist. Chemical and biological assays were carried out with high-volume and mist-spray formulations of DDT. Effective contact action but poor residual action was obtained. The chemical assay data indicated that this was due to a rapid loss of deposit from treated coconut-spadix and leaf surfaces mostly by absorption. These results indicate that in practice very thorough coverage of palms, to ensure adequate contact action, will be necessary. No field trials have so far been carried out with mist-spray applications and the economics of such an operation on scattered plantations on a number of islands are extremely doubtful.

Some detailed observations have also been made on small plots in nutfall areas to assess:—

(a) the degree of control of *Amblypelta* that would be necessary by direct spraying in order to ensure full crops.

(b) the reliability of the percentage of young fallen nuts bearing *Amblypelta* feeding scars as a measure of crop loss resulting.

A conclusion from this work is that individual palms vary considerably in their ability to produce a crop when subject to attack by *Amblypelta* and this point might well repay further study.

Brontispa longissima (Gestro)

The larvae and adults of this Hispine beetle sometimes cause severe damage to young coconut palms during the first ten years or so of their life, and when the first European-type plantations were being established in the Solomons it was a serious pest. Recent trials with insecticides have shown that it can be readily and economically controlled by routine spraying at six-weekly or longer intervals. Of several insecticides tested 0·15 per cent. dieldrin proved the most effective. Where replanting is now undertaken this pest need no longer be feared.

Pests of Cacao

A scheme is now under way to establish cacao as a second cash crop in the Solomons. The first plantings commenced bearing in 1957–1958 and there are a few older trees.

A close watch has been kept for the appearance of insect pests, and damage of importance has so far been noticed attributable to the following species.

Amblypelta cocophaga China

This is the same species of Coreid as is primarily responsible for immature nutfall of coconuts. Many wild host plants have been recorded, and damage to cacao has been observed in several localities. This takes the form of distortion and stunting of fruits and also deformation and die-back of terminal shoot growth. No attempts at control have so far been made.

Pantorhytes biplagiatus (Chev.)

The larvae of this wingless weevil bore into the wood of the cacao tree rendering it susceptible to mechanical damage and generally weakening growth. Adults feed on the foliage but the effect is not important. Little work on control measures has yet been carried out.

Xyleborus fornicatus Eich.

This pest was first recorded in 1958, when, in association with fungal attack, complete death of a number of trees, and destruction of branches on others, was caused.

All of the above pests present a potentially serious threat to the successful establishment of cacao in the Solomons and need further investigation.

Termites

Collections of termites have been made over the period under review, both from infested timber in buildings and from natural habitats. Twelve species have been recorded, of which five have occurred in damaged buildings. The dry wood termite *Cryptotermes domesticus* (Hav.) has been recorded from movable items of furniture on several occasions and now seems to be firmly established in the Protectorate.

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CANADA

REVIEW OF ECONOMIC ENTOMOLOGY

1. ORGANISATION OF ENTOMOLOGICAL RESEARCH, AND REVIEW OF RESEARCH COMMON TO AGRICULTURE AND FORESTRY

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Among the organizational changes affecting entomology during the period under review, perhaps the most important was the reorganization of research in the Canada Department of Agriculture, effected April 1, 1959. Previously, federal agricultural research was organized under two services, the Experimental Farms Service and the Science Service, with entomology the principal subject-matter of two divisions of Science Service—the Entomology Division and the Forest Biology Division. The reorganization effects a consolidation of the two former services to form the Research Branch under direction of a senior officer with rank of Assistant Deputy Minister. Entomology and forest biology are represented in a Programme Directorate charged with the co-ordination of the national programme of agricultural research. Forest entomology remains in the line-type organisation of the Forest Biology Division, and is organised in essentially the same way as previously (see Part 3). But agricultural entomology, linked as it is with many other facets of agricultural research, is under the immediate direction of the heads of the largely autonomous regional establishments and national institutes. Three of the newly formed national institutes are concerned solely with entomological research, and agricultural entomology is integrated into the research programmes at 17 of the regional establishments. The objective of the reorganization is to provide unified direction and co-ordination of agricultural research and to foster a multi-discipline attack on the problems of Canadian agriculture. The Research Branch comprises about 1,100 scientists of whom 340 are entomologists.

Support for entomological research was augmented by a scheme of Post-Doctorate Fellowships sponsored by the National Research Council, and tenable in universities or government laboratories for periods of one or two years. The Fellowships are competitive and cover many disciplines, but a number of entomologists from abroad have received support under this scheme. The Defence Research Board Advisory Committee on Entomological research has continued to support research in the universities and the Canada Department of Agriculture, mainly on problems associated with biting flies. The Canada Department of Agriculture supports a scheme of Extra-Mural Research Grants in Canadian universities and provincial research agencies, and a number of entomological projects are supported by this means.

Facilities for entomological research have continued to improve. In the Canada Department of Agriculture, entomologists have been accommodated in 10 new laboratories constructed during the period, and several more are in progress or planned. Thus, the building programme begun some 10 years ago will soon see most federal entomologists housed in modern laboratories, usually in association with other disciplines. In the universities, too, new facilities for research and teaching have been constructed at several centres and more are projected for the immediate future.

The Entomological Society of Canada was strengthened by the formation of three additional regional societies. The national body now comprises a federation of 7 regional societies with a total membership of 625. A highlight of the period was the first formal joint meeting of the Entomological Society of Canada and the Entomological Society of America at Detroit in 1959.

In contrast to the immediate post-war period, the 1954-59 period has been characterised by consolidation rather than expansion. Emphasis has been on improvement of research facilities, higher academic standards for staff, and a more fundamental approach to the solution of entomological problems. Nine universities now offer post-graduate training to the Ph.D. level in entomology. Many entomologists in the federal service have received financial aid under a scheme of educational leave which permits them to return to university for higher degrees; senior staff with established authority in a field of entomological research are supported for a year's transfer to work with a world authority in their speciality. To make better use of this increasingly well-qualified staff, the Research Branch of the Department of Agriculture commits most new staff positions to technical supporting staff.

RESEARCH COMMON TO AGRICULTURE AND FORESTRY

Systematics and Genetics

Research in systematic entomology is centred in the Taxonomy Section of the Entomology Research Institute, Canada Department of Agriculture, Ottawa. The Canadian National Collection of Insects is under the custody of this Institute whose staff of 21 research officers contribute to the Collection by systematic surveys, and use it for their research and for an identification service available to entomologists in the Research Branch, the universities, and the general public. Other important collections and centres for research in systematic entomology exist in several of the universities and in two of the provincial museums.

The Canadian National Collection now exceeds 3,000,000 pinned specimens, comprising some 56,000 segregated species and subspecies. The Collection is richest in Nearctic material but representation from the Palaearctic and other regions is rapidly increasing. In the period under review, emphasis centred on collections of Pyralidae, Scarabaeidae, several families of Hymenoptera, Diptera, Hemiptera, Siphonaptera, and Acari.

An intensive programme of surveys has continued to improve our knowledge of Canadian insects and their taxonomic relationships. The Northern Insect Survey, begun in 1947, has now covered about 70 localities in the Arctic and Subarctic. Though biting flies were of special interest in the North, the collections have covered all orders. Several areas in the temperate parts of Canada and the United States have been surveyed for material that will expedite the development of the Collection as a taxonomic tool, and more specialised surveys in Mexico, Papua, and New Guinea were undertaken for more restricted objectives. The Forest Insect Survey (see Part 3) has contributed much to the development of the Collection, especially in representation of forest pests, their parasites and predators.

Taxonomic research was concerned mainly with the orders Coleoptera (especially Chrysomelidae, Scarabaeidae, and Elateridae), Lepidoptera (especially Pyralidae, leaf-mining families, Noctuidae, and larvae of Tortricoidea), Hymenoptera (especially Ichneumonoidea, and a catalogue of Chalcidoidea), Diptera (especially Simuliidae, Lonchaeidae, Tabanidae, Syrphidae, and Muscidae), Hemiptera (especially Aphididae and Miridae), and Siphonaptera. Of the large number of papers published by systematists during the period, most were standard descriptive or revisionary studies but a number were important contributions to zoogeography or to evolutionary theory. Of special importance were eight monographs published as Supplements to *The Canadian Entomologist* as follows: Nearctic *Agriotes*; Leafhoppers of Canada and Alaska; New World *Chrysomela*; Elliptoid-eyed species of *Schinia*; Nearctic Archipinae; Acridoidea of Southern Alberta, Saskatchewan, and Manitoba; Larvae of North American Olethreutidae; and Male Genitalia of Miridae. Also important were a biographical study of Canada as an Environment for Insect Life, and a Symposium on Distribution of Arctic and Subarctic Insects.

Cytogenetic studies have clarified our knowledge of speciation in a group of Canadian black flies and defined several species previously unrecognised. Cytogenetic analyses have also established the chromosomal steps by which the six North American species of the coccinellid genus *Chilocorus* have arisen, and have revealed certain species that are difficult or impossible to separate by conventional taxonomic methods. On the other hand, it seems probable that the polymorphisms distinguishing certain " species " in the curculionid genus *Pissodes* are causally related through introgressive hybridisation.

The genetics of pigment polymorphisms is being used as a means of studying the genetic structure of insect populations. It has been shown that egg coloration in 15 species of diprionid sawflies results from different combinations of two basic egg pigments; the resultant egg colour is species diagnostic in most cases. The genetic control and biological significance of these egg pigments is being studied. In the budworms, *Choristoneura fumiferana* (Clem.) and *C. pinus* Free., a polymorphism of pupal haemolymph pigments is determined by a genetic balance system similar to the balance systems that determine sex in general. Several species and subspecific populations are distinguished by allelic potencies and allelic frequencies at the controlling loci, leading to an extensive range of genotypes. The differential survival and selective values of these genotypes and the physiological implications of the different pigments are under study.

Chromosome morphology, serology, and paper chromatography have been applied to problems in the taxonomy of species of *Cryptolestes*, *Aëdes*, and geographical forms of *Psila rosae* F.

Studies are in progress on the genetics of resistance to insecticides in agricultural insects and insects of medical importance.

Biological Control

In the search for useful biological control agents, more than 1·5 million specimens of parasitic, predacious, and weed-feeding insects were imported from 17 foreign countries during the period under review, and 875,000 specimens of 50 species were liberated in Canada. Imported biological control agents were liberated against the following pest species in Canada: balsam woolly aphid, *Adelges piceae* (Ratz.); European pine shoot moth, *Rhyacionia buoliana* (Schiff.); European pine sawfly, *Neodiprion sertifer* (Geoff.); European winter moth, *Operophtera brumata* (L.); spruce budworm *Choristoneura fumiferana* (Clem.); sweetclover weevil, *Sitona cylindricollis* Fahr.; alfalfa weevil, *Hypera postica* Gyll.; European earwig, *Forficula auricularia* L.; and St. John's wort, *Hypericum perforatum* L. A number of the species liberated became established, but it is too soon to decide if these establishments are permanent and if significant control will result.

The natural enemies of other Canadian pests are being investigated abroad as a preliminary to biological control attempts in Canada. These pests include: larch sawfly, *Pristiphora erichsonii* (Htg.); wheat-stem sawfly, *Cephus pygmaeus* (L.); marsh cranefly, *Tipula paludosa* Mg.; the tortricid moth *Cnephasia virgaureana* (Tr.); the tineid moths *Swammerdammia caesiella* Hb. and *S. lutarea* Haw.; codling moth, *Carpocapsa pomonella* (L.); tansy ragwort, *Senecio jacobaea* (L.); Canada thistle, *Cirsium arvense* L.; and toadflax, *Linaria vulgaris* Mill.

Studies on the ecology, behaviour, and control value of major taxonomic groups of biological control agents, notably of phytoseiid mites, spiders, ants, anthocorid Hemiptera, entomophilic nematodes, and pathogens, indicated, for example, that: the value of predacious mites in controlling phytophagous mites on different fruit trees largely depends on the winter survival of the predators and on the degree to which they feed on plant materials; the nematode DD136 can be used to control mosquitoes, as well as various crop pests; insects can be immunised against bacterial diseases by doses of antigens; and *Coccobacillus acridiorum* d'Herelle is not an effective pathogen to locusts, despite published reports to the contrary.

Investigations with experimental host-parasite and predator-prey populations indicated that the fluctuations of two interacting species are not entirely determined by the influence of density on the increase of both populations.

In work on factors that affect behaviour and reproduction it was found, for instance, that: the oviposition rate of a parasite is much influenced by atmospheric electricity; mosquito larvae could be killed by application of ultrasonics; odours from the host foodplant and from other plants strongly influence host-finding by parasites; the kind of food obtained by adult parasites has a major influence on numbers of eggs laid, adult longevity, and survival of progeny, and therefore on whether or not a parasite can establish itself in a locality.

Other studies yielded information on the histology of the encapsulation of parasites within host insects; effects of temperature on survival and reproduction of parasites; bionomics of the natural enemies of biting flies, grasshoppers, legume weevils, the European pine shoot moth, and certain noxious weeds.

Insect viruses have proven to be effective control agents, especially against forest insects. *Neodiprion sertifer* (Geoff.) has been reduced to minor status through the planned introduction of polyhedrosis virus supplemented by chemical insecticides. It has been demonstrated that the native sawfly *Neodiprion lecontei* (Fitch) can be controlled by the introduction of a virus. Three virus diseases of the spruce budworm, *Choristoneura fumiferana* (Clem.), have been under intensive study with promising results from combined infections (see Part 3).

Studies on fungi-attacking insects have elucidated the effects of various nutrient elements on growth and sporulation and enabled the production of spores almost at will.

Basic studies on the mode of action of bacteria pathogenic to insects have revealed that the lethal effect of the *Bacillus cereus* group results from a crystalline protein produced in the bacterium. Further studies have shown the importance of the pH of the insect mid-gut in determining the release, and hence the specificity, of the toxin. In related studies, *Bacillus cereus* which is pathogenic to insects with midgut pH values of 7 to 8·5, has been cultured serially in media of increasing pH, and a strain capable of growing at pH 10·5 has been selected. It is expected to be pathogenic to insects with comparable midgut alkalinity. A commercial preparation of *B. thuringiensis* is now available and is being tested in field trials against agricultural and forest pests (see Parts 2 and 3).

Physiology

Insect nutrition remained an active field for Canadian insect physiologists. Rearings on chemically-defined diets enabled the nutritional requirements for growth and development of certain parasitic Diptera to be defined qualitatively and quantitatively, and many of the biochemical mechanisms involved were worked out. Histological studies revealed that gross tissue changes accompanied nutritional deficiencies. For the first time, a parasitic Ichneumonid was reared on an artificial diet. A number of species of Coccinellids were kept alive for more than a year on artificial diets, and some of them reproduced on these diets. The blowfly, *Phormia regina* (Meig.), was successfully reared on an artificial diet.

The development of chemically-defined diets for two species of root maggots marks the first successful attempt to rear phytophagous insects on such diets. Other studies with phytophagous insects have shown that certain sugars and amino acids, known to occur in plants, excite gustation in grasshoppers when presented singly, and the effect is potentiated synergistically with certain combinations of these substances. Qualitative and quantitative studies of feeding by Aphids in relation to the resistance of the host plant are referred to in Part 2. Larvae of *Ctenicera aeripennis destructor* (Brown) were reared in aseptic culture with synthetic diets containing casein. Freeze-drying enabled the storage of plant materials grown at one time under uniform conditions and subsequently used as food for insects over a long period.

An important contribution to the methods for studying insect nutrition was the demonstration that feeding carbon-labelled sugar resulted in the labelling of non-essential amino acids and absence of the label on essential amino acids.

Metabolic studies have shown that hexokinase and other glycolytic enzymes are present in all stages of the sawfly, *Cephus cinctus* Nort. Three metabolic systems for energy production were found in the egg, larval and adult stages of *Phormia regina* (Meig.). Investigations of the metabolism of houseflies and roaches have shown that two main channels for carbohydrate utilisation are available: firstly glycolysis and the Krebs cycle; secondly the pentose phosphate cycle. Under anaerobic conditions α-glycerophosphate and pyruvic acid, and not lactic acid, are the main end-products of glycolysis in insect muscle. The glycolytic pattern is determined by the relative activities of the two enzymes, lactic dehydrogenase and α-glycerophosphate dehydrogenase.

Current studies in the histology and function of insect organ systems involve: oenocytes as possible endocrine glands; the glands in bees responsible for the production of royal jelly; the excretory system of Lepidoptera during the pupal-adult transformation. Histochemical studies of the salivary glands of *Oncopeltus fasciatus* (Dallas) have shown that they produce an array of enzymes including amylase, protease, invertase, and a non-specific esterase, each of the various lobes having their specific complement. Direct observation of blood cells in the wing veins of *Blaberus giganteus* (L.) has shown that the haemocytes move, independently of the circulation of the blood, by two types of amoeboid movement. Circulation becomes less active in older insects, principally because the haemocytes change their form and settle on the walls, thus occluding the vein cavity.

Knowledge of cold-hardiness in insects has been advanced by the application of the principles of nucleation to the super cooling and freezing of insects and by the finding that insects synthesise and use glycerol to avoid the injurious effects of internal freezing.

Studies on the physiological basis for the insecticidal action of certain organophosphates has led to the conclusion that the accumulation of the neurohormone, acetylcholine, when the normal controlling mechanisms are blocked, is a " biochemical lesion " in poisoning. Accumulation of acetylcholine was also found in the nerves of roaches poisoned with DDT or with dieldrin. The blood of DDT- or dieldrin-treated roaches produced intense activity in nerve preparations of untreated insects, an action due, in part, to a factor released from certain endocrine glands of the poisoned insect. The active agent produced by the metabolism, in plant, mammal or insect, of the systemic insecticide schradan is considered to be a methylol derivative and not the oxide as at first thought. The impermeability of the nervous system of tolerant insects to the methylol derivative, and to certain other compounds, is a factor in the selectivity of insecticidal action. Differences in the metabolism by susceptible and tolerant species are a cause of the selective toxicity of malathion. On the basis of this knowledge a plan for the molecular design of selective insecticides has been proposed and used to prepare several new compounds, insecticidal yet with low mammalian toxicity.

2. AGRICULTURAL ENTOMOLOGY

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This part covers the principal developments in all phases of agricultural entomology in Canada during the period 1954 to 1959 except those basic studies that have been reported in Part I.

The reorganisation of the Canada Department of Agriculture in 1959 described in Part I did not affect the number of establishments or staff engaged in entomological investigations on crop pests in Canada. In 1954 a new laboratory was opened at Guelph, Ont., for work on livestock insects and in 1955 another was opened at Vancouver, B.C., for work on crop insects. Most of the staff at Brandon, Man., was transferred to Winnipeg, Man., in 1957, and the remainder in 1959. Work on fruit insects at Morden, Man., and on stored product insects at Ottawa was discontinued in 1958 with the transfer of personnel from those establishments to the Winnipeg laboratory.

Researches were continued along lines and at levels substantially similar to those reported in the 1948–1954 review, and were concerned largely with uses of the newer organic insecticides against various pests. At the same time, studies in physiology, behaviour and ecology were intensified.

At least 25 species of insects and mites were recorded as pests for the first time in Canada; some of these are creating serious problems and several others are potentially important.

FIELD CROP AND VEGETABLE INSECTS

Most of the research on insect pests of field and vegetable crops was concerned with uses of organic hydrocarbon and organophosphorus insecticides. However, ecological and physiological studies, especially on diapause, development, host plant relationships, and population dynamics of various pests were intensified.

Widespread and serious outbreaks of the following insects occurred: the armyworm, *Pseudaletia unipuncta* (Haw.), on grains and grasses from Saskatchewan to Newfoundland in 1954; the corn leaf aphid, *Rhopalosiphum maidis* (Fitch), on barley from Alberta to Newfoundland in 1955; the six-spotted leaf-hopper, *Macrosteles fascifrons* (Stål), and aster yellows, in vegetables from Alberta eastward and in flax in western Canada in 1957; soil-inhabiting cutworms in western Canada from 1957 to 1959; and grasshoppers in western Canada late in the period.

Grasshoppers

Grasshopper infestations increased from non-economic levels in 1954 to moderate or severe from 1957 to 1959 over much of some 50,000 square miles infested in the southern farming areas of the Prairie Provinces and on British Columbia rangelands. Damage was kept at low levels by general use of aldrin, dieldrin or heptachlor sprays at a cost of as little as 18 cents for insecticide per treated acre.

Studies published in 1956 indicated high positive correlations of adult grasshopper densities with average temperature of the previous summer and of June of the current year, and high negative correlations with rainfall during the previous August and September. Further studies indicated high positive correlations between grasshopper densities and mean monthly temperatures during May to September of the previous three years, and high negative correlations between total precipitation during April to August of the previous two years. Experiments showed that survival and fecundity of the migratory grasshopper, *Melanoplus bilituratus* (Wlk.), are related to date of hatching; those hatching in May produced up to ten times as many eggs as those hatching in July.

Mixtures of graminaceous plants, such as wheat or brome grass, and broad-leaved plants, such as common mustard or dandelion, resulted in much higher survival and fecundity of *M. bilituratus*, whose main habitat is cereal grain fields, than did food plants in pure culture. This indicates that grain fields free from weeds are less favourable habitats than weedy fields for this grasshopper. Wheat high in nitrogen, and also wheat low in phosphorus, favoured development, survival and fecundity of this species. Native grasses were generally unsuitable for *M. bilituratus.* Oats, although nutritionally adequate, were a poor food because the grasshoppers would not eat enough of them. The clear-winged grasshopper, *Camnula pellucida* (Scudd.), showed marked differences in ability to survive on different native and introduced grasses.

In eastern Manitoba, changes in the vegetation caused by drainage, cultivation and roadbuilding have brought about changes in the relative abundance of grasshoppers. For example, *C. pellucida* became a pest in 1900 following an increase in *Agropyron smithii* Rydb., and *Melanoplus bivittatus* (Say) in 1932 after broad-leaved weeds became common. Farm and roadbuilding practices now favour the maintenance of *M. bivittatus* but are causing a decline in numbers of *C. pellucida* because they destroy the preferred habitats of this species.

M. bivittatus and probably one other species, each of which has a one-year life cycle in most of Canada, have a two-year cycle at high altitudes and latitudes in British Columbia. Two winters are passed in the egg stage and the active stages occur only in even-numbered years.

Cutworms

In recent outbreaks of soil-inhabiting cutworms, excellent control was obtained with sprays of any of the commonly available insecticides, though endrin was generally the most effective. In British Columbia, mixing the insecticide with the soil gave better protection to asparagus and other vegetables than did surface applications, and the percentage mortality of cutworms was higher in moist than in dry soil.

Against the climbing cutworms, *Mamestra configurata* Wlk. on flax and rape and *Heliothis ononis* Schiff. on flax, DDT was more effective than several other insecticides. Considerable new information on ecology of several species of cutworms was obtained; *e.g.*, infestations of *M. configurata* were usually highest in weedy fields because it laid its eggs on weeds in preference to the crop plants, and infestations of *Euxoa ochrogaster* (Gn.) were also heaviest in areas that were weedy during the moth flight.

Wireworms

General use of aldrin, dieldrin, heptachlor or chlordane in soil applications for vegetables and other row crops, and in seed dressings for cereals, have reduced losses caused by wireworms to insignificance throughout Canada. A single soil application provides protection for 3 to 5 years or more, depending on the species of wireworm involved.

Treatment of seed with lindane, with or without an organic mercury fungicide, increased common root rot in wheat seedlings. Treatment with aldrin or heptachlor did not increase infection, and addition of a fungicide decreased the severity of the infection.

In Nova Scotia, application of chlorinated hydrocarbon insecticides to grasslands gave satisfactory reduction in numbers of *Agriotes sputator* (L.) and increased the yield of forage for several years after treatment.

In laboratory studies mature larvae of *Ctenicera aeripennis destructor* (Brown) preferred higher soil temperatures and lower soil moisture than those of *C. aeripennis aeripennis* (Kby.) or *Hypolithus bicolor* Esch. This supports field observations that *H. bicolor* increases in numbers when soil moisture is high, whereas *C. destructor* does not.

A sex attractant obtained from virgin females of *Limonius californicus* Mann. is useful in detecting infestations of this species. The substance is specific and at room temperature is stable for at least a year.

Studies on methods of sampling wireworm populations confirmed the British experience that flotation methods are more reliable than soil sifting. Other studies provided criteria for the number and distribution of sampling units required for reliable estimates of wireworm populations.

Tuber Flea Beetle—*Epitrix tuberis* Gent.

This flea beetle is still extending its range in British Columbia, where it is a serious pest of potatoes. It sometimes also damages tomatoes severely but it survives and reproduces in greater numbers on potato. Treatment of the soil with insecticides gives better control than treatment of the foliage. One soil application is effective for two to three years.

Root Maggots—chiefly *Hylemya* spp.

Several species of root maggots continued to be among the most serious pests of vegetables. In 1958, in Ontario and British Columbia, strains of the onion maggot, *Hylemya antiqua* (Meig.), were highly resistant to aldrin, dieldrin and heptachlor, which hitherto had given excellent control. Tests and practical experience showed that ethion and Trithion gave satisfactory protection against the resistant maggots. Heptachlor and aldrin were generally effective against other root maggots when applied on the seed, in the seed furrow, as a narrow band mixed with the top layer of soil, or as drenches or dusts around transplants. Placing the insecticide below the seed has given better protection against the cabbage maggot than surface applications because this treatment destroys fewer of the natural enemies of the maggots. Insecticide seed treatments have generally been effective against *Hylemya cilicrura* Rond. in vegetables, and addition of a suitable fungicide results in better stands than where the insecticide alone is used. In tobacco, however, severe infestations of *H. cilicrura* appeared in 1958 and 1959 where aldrin or heptachlor had been used to control wireworms because resistant strains of the maggot had developed.

The maggot, *Tetanops myopaeformis* (Roed.), became an increasingly widespread and serious pest of sugar beets in light soils in Alberta and Manitoba. One pound of heptachlor or aldrin per acre, mixed with fertiliser and applied in the seed furrow, increases yields up to two-and-a-half times. Laboratory tests showed that damage to beet by insecticide-fertiliser treatments were attributable to an insecticide, to the solvent, especially heavy aromatic naphtha, or, in dry soils, to interference by the fertiliser with the supply of moisture to the seed.

European Corn Borer—*Ostrinia nubilalis* (Hb.)

Studies in Ontario showed that diapause occurs in the European corn borer when larvae entering the last instar are exposed for 3 weeks to a temperature of 65° F. and a light period of less than 14 hours per day, and that it is prevented by longer photoperiods or higher temperature. Studies of weather records showed that occurrence of two generations of the borer per year in south-western Ontario was associated with warmer than normal weather during spring and early summer, so that many of the larvae matured before day length was reduced to less than 14 hours. In Quebec, life table studies are providing detailed information on the factors affecting abundance of the borer.

Granular insecticides were as effective as sprays against the borer in sweet corn and did not leave toxic residues in the kernels.

Caterpillars on Cabbage

The diamondback moth, *Plutella maculipennis* (Curt.), has been abundant on cruciferous vegetables in eastern Ontario in the past 10 years. Depending upon temperature, there are four to six generations per year. Life tables, developed for 10 complete generations, show that rainfall and three species of parasites are the most important factors regulating numbers of the insect.

In 1955, in Ontario, the cabbage looper, *Trichoplusia ni* (Hb.), developed a strain resistant to DDT. Chemical control schedules for caterpillars on cabbage now include endrin, Phosdrin, or a mixture of malathion and Perthane. Commercial spray formulations containing spores of *Bacillus thuringiensis* Berliner showed considerable promise for control of one or more species of the caterpillars. A polyhedrosis virus new to Canada caused considerable mortality of the cabbage looper in the field in Ontario and Quebec in 1959.

Six-spotted Leafhopper—*Macrosteles fascifrons* (Stål), and Aster Yellows

Aster yellows, spread by the six-spotted leafhopper, caused severe losses of susceptible vegetables annually in eastern Canada, and in 1957 reduced yields of flax about 15 per cent. in the Prairie Provinces. Extensive studies in Ontario and Manitoba showed that, although the leafhopper overwinters in the egg stage on fall rye and winter wheat, most of the infestations are produced by adult leafhoppers brought northwards into Canada by strong movements of warm air masses in May. A few of these migrants are viruliferous. Several species of weeds are reservoirs of the disease. Three or four generations are produced each year, the peak numbers occurring in late summer. Early crops escape serious infestation and infection but midsummer and later crops are often destroyed by the yellows. Despite extensive studies, no practical method of protecting susceptible crops has been developed. Though insecticides kill the leafhoppers present at treatment, reinfestations of viruliferous leafhoppers from surrounding untreated grassland and other areas recur throughout the season.

Aphids

Studies on the distribution, ecology, physiology, mode of feeding, biotypes and control of various Aphids were intensified.

The enzyme pectinase was found in the saliva of some species of Aphids and not in others; different forms of a species may or may not have it. The enzyme usually occurred in wingless but not in winged forms. The enzyme was usually present in those Aphids that insert the stylets between cells, but not in those that insert them through cells.

Viruses that Aphids acquire and transmit during brief probes adhere to the tips of the stylets. Such viruses are acquired and transmitted as the stylets penetrate the epidermal layer of cells. The virus infection can be stopped in early stages by irradiating the plants with ultra-violet radiations or spraying them with trichothecin. These results suggest that effective chemotherapeutic treatments may be developed to protect plants against infections by non-persistent viruses.

Although the corn leaf aphid often occurs in economic infestations in eastern Canada, it has only once, in 1955, been a pest in western Canada. In that year this species occurred in severe infestation on late-seeded barley from Newfoundland to Alberta and, where control measures were not taken, caused severe crop losses. Malathion was effective. The Aphid does not become established on barley after the crop is in the boot stage.

In three years of study in British Columbia no serious reductions in yield of grain could be attributed to moderate to severe infestations by several species of Aphids, chiefly *Macrosiphum avenae* (F.) on oats.

The life histories, ecologies and host relations of *Pemphigus betae* Doane and closely related species were studied extensively in Alberta. Other studies in Ontario on identification, life histories and roles of various Aphids as vectors of the virus disease yellow dwarf in barley and of tobacco etch, were initiated.

Treatment of pea seed with Di-syston and thimet gave promising control of the pea aphid, *Acyrthosiphon pisum* (Harr.), without affecting germination or leaving detectable residues in the crop. Neither systemic nor contact insecticides applied against vectors of tobacco etch prevented spread of the virus even though mortality of the vector was high. Systemic insecticides such as thimet, dimethoate and Di-syston in granular soil applications in the crop row showed promise against Aphids and other sucking insects attacking potatoes. However, so far, residues in the crop have not been eliminated. Some of these treatments also controlled the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), and flea beetles.

Forage Crop Insects

The alfalfa weevil, *Hypera postica* Gyll., first recorded in Canada in 1954, has spread through the alfalfa-growing areas of southern Saskatchewan and Alberta, but infestations were still sub-economic in 1959. The weevil has apparently survived in this area because it has developed a strain that does not become active in the spring until danger from frost is past.

Studies showed that the clover seed midge, *Dasyneura leguminicola* (Lint.), has two generations annually in Ontario, that half of the first generation, and all of the second, hibernate as mature larvae, and that a few larvae remain dormant up to three years before pupating. Harvesting the first crop of red clover in mid-June, induced the second crop to bloom early enough to escape serious damage to the seed by the second generation.

Studies on three new species of plant bugs, *Liocoris unctuosus* Kelton, *L. borealis* Kelton and *Plagiognathus medicagus* Arrand, which infest alfalfa in northern Saskatchewan, showed that all species have one generation per year; that *Liocoris* species overwinter as adults and *P. medicagus* as eggs in alfalfa stems; and that these insects may cause serious reductions in seed yields. These pests can be satisfactorily controlled in seed-fields by a single application of dieldrin, heptachlor or DDT when the alfalfa is in the early-bud stage. Burning crop residues in the spring will also control *P. medicagus*.

Studies were continued in the Prairie Provinces and Ontario on pollinators of forage crops: on foraging behaviour of honey bees, bumble bees and leaf-cutter bees and on their life histories and ecologies. In general, bumble bees were the most effective native pollinators; they were most effective in rape and sweet clover, less useful in altaswede red clover, and least useful in alfalfa. Only where Megachilids were especially abundant was alfalfa seed produced as successfully as that of altaswede red clover. Limited success was achieved in inducing bumble bees to accept artificial domiciles and in establishing the colonies near or in the crop to be pollinated.

Resistance of Plants to Insects

The major factor in resistance of the bread wheats, Rescue and Chinook, to the wheat stem sawfly, *Cephus cinctus* Nort., is the pith that makes the stem solid. Solidness may, however, be reduced by environmental factors such as cloudy weather in the latter half of June; this was confirmed experimentally by shading the plants. Resistance also varies between and within internodes. The pith does not differ from the stem wall in dry matter or nitrogen content. Treating the stems with gibberellic acid reduced survival of the larvae by at least 50 per cent.

Stem solidness is governed genetically by the interaction of various genes. A set of seven chromosomes not possessed by the durum Golden Ball makes Rescue less solid than Golden Ball in the top internode. At least eight genes in other chromosomes affect stem solidness in Rescue. The work of identifying the chromosomes involved has been almost completed.

Studies of resistance in peas to *Acyrthosiphon pisum* (Harr.) showed that the rates of ingestion and assimilation of nutrients and of excretion of honey dew were proportional to the susceptibility of the variety; the concentration of free amino-acids and amides was higher in Aphids that fed on susceptible plants than in those that fed on resistant plants. Several biotypes of the Aphid occur; those from alfalfa were more injurious to peas than those from clover. The nutritive values of various dietary constituents were determined by feeding them to the Aphid through plant cuttings. This method may be useful in studies of resistance in plants to Aphids.

Seven varieties of the onion, *Allium fistulosum* L., were found to be less attractive to the onion maggot than four varieties of *A. cepa* (L.), and Beltsville Bunching, a hybrid variety, was intermediate in attractiveness. A degree of resistance to the cabbage maggot was found in the Laurentian and Wilhelmsburger varieties of rutabaga. In the Laurentian variety, study of a selection of highly resistant plants showed that inheritance of resistance to the maggot was polygenic. Differences in susceptibilities of cabbage varieties to root maggots were also demonstrated, but are of doubtful economic importance. Studies are under way to find and develop other varieties of crop plants resistant to insect pests.

Narcissus Bulb Fly—*Lampetia equestris* (F.)

Treatment of narcissus bulbs at planting time by one of the following methods gave 91–100 per cent. control of the narcissus bulb fly for three years: soaking the bulbs in hot water (110° F.) and formalin as for control of the bulb nematode, with heptachlor added; soaking them for 10 minutes in a cold water emulsion of aldrin, dieldrin, chlordane or heptachlor; or dusting or spraying them in the open furrow with aldrin, dieldrin or heptachlor. DDT and lindane were not effective, and lindane adversely affected growth of narcissus.

Greenhouse Whitefly—*Trialeurodes vaporariorum* (Westw.)

Studies of fungicides applied to greenhouse cucumber showed that maneb was toxic to larvae and adults of the greenhouse whitefly.

FRUIT INSECTS

Highlights of fruit-insect work include development of strains resistant to DDT by the codling moth, *Carpocapsa pomonella* (L.), and to DDD by the red-banded leaf roller, *Argyrotaenia velutinana* (Wlk.); initiation of a study on population dynamics of apple pests in Quebec, and another on possibilities of controlling the codling moth by the release of sterile males.

Harmonizing Chemical and Natural Control

The investigations in Nova Scotia on methods of harmonizing biological and chemical control of apple pests, summarized in the 1954 review, were continued and broadened to include studies on the factors that maintain faunal balances. Each year more growers adopted the integrated programme and at present about 90 per cent. follow it. Tentative conclusions from these studies are:

1. The method must be adopted over a large area, and only after some years will the full benefit of the programme be realized. There has been a gradual improvement in the control obtained in Nova Scotia over the past 12 years.

2. Close liaison between research workers, advisory officers and growers is essential. The researcher must understand the mechanisms of natural control, how these may be manipulated to advantage, and how and when to use chemicals. The advisory officer must appraise the pest problems as they develop and advise growers of the methods necessary to achieve control.

3. The 73 species of apple pests recorded in Nova Scotia may be divided in three general groups: (a) 53 species whose numbers are always at sub-economic levels unless the natural enemies are killed by artificial means; (b) 3 species whose numbers vary with the amount of suitable food available; and (c) 17 species that are usually but not always kept in check by natural agents; chemicals must be used at times to prevent damage by one or more of these insects.

From 1954 to 1959, tests of 32 pesticides showed that ryania, nicotine sulphate, lead arsenate and ovex were least destructive to beneficial Arthropods. These are the chemicals used in the integrated programme.

Life-table studies of some Arthropods of economic importance in Quebec apple orchards have been in progress since 1957 in plots where no insecticides are used. The most important mortality factors of the eye-spotted bud moth, *Spilonota ocellana* (D. & S.), and the pistol casebearer, *Coleophora serratella* (L.), were winter temperatures and birds; and of the fruit-tree leaf roller, *Archips argyrosipilus* (Wlk.), birds and dispersal of larvae by wind. Fungicides differed greatly in their effects on mites; glyodin reduced the numbers of all mites present, captan favoured an increase of *Panonychus ulmi* (Koch) but kept predacious mites at low levels, and Cyprex kept numbers of *P. ulmi* at a much lower level than Niacide, Phygon or Thylate.

Ecological studies in peach orchards in Ontario showed that mites would be much less troublesome if DDT, parathion, Sevin and other broad-spectrum insecticides were not used, and that infestations of the cottony scale, *Pulvinaria vitis* (L.), would be less destructive if DDT were not used. However, one or more of these insecticides are required to control the oriental fruit moth; hence a " harmonized " control programme cannot be achieved until an insecticide effective against the fruit moth, but harmless to natural enemies, is discovered.

Oriental Fruit Moth—*Grapholitha molesta* (Busck.)

To keep the residue below the tolerance of 7 p.p.m., DDT on peach must not be applied later than 25 days before harvest. This has failed to give adequate protection of the ripening fruit in some years. A spray of Guthion 21 days before harvest, or of Sevin 14 days before harvest, gave good control without leaving excessive residues.

Parasitism of twig-infesting larvae by the introduced species *Macrocentrus ancylivorus* Roh. was generally higher in the Niagara Peninsula for the 12–year period during which DDT and parathion were used than for the previous nine years.

Peach Tree Borers—*Synanthedon pictipes* (G. & R.) **and** *Sanninoidea exitiosa* (Say).

Recent investigations in Ontario showed that three sprays of parathion plus malathion, endrin or Thiodan were effective against the lesser peach tree borer, *Syn. pictipes*, and the peach tree borer, *San. exitiosa*, when applied at 3-week intervals, the first being applied 5 to 12 days after the last spray against the plum curculio. A satisfactory control for *S. pictipes* was previously not available in Ontario.

Cherry Fruit Flies—*Rhagoletis cingulata* (Loew) **and** *R. fausta* (O.S.).

In British Columbia the standard schedule of four sprays of lead arsenate has allowed up to 5 per cent. of cherries to be infested by fruit flies and left unsightly residues. Investigations completed in 1959 showed that two sprays of diazinon applied one and two weeks before harvest gave superior control and left no visible residue. The diazinon killed larvae of all stages within the cherries.

Red-banded Leaf Roller—*Argyrotaenia velutinana* (Wlk.)

Since 1957 it has become increasingly difficult to control the red-banded leaf roller with DDD because strains moderately resistant to this insecticide have developed. Also, the trend from conventional dilute spraying to air-blast concentrate spraying has resulted in poorer control because of less spray deposit on the undersides of the leaves.

Codling Moth—*Carpocapsa pomonella* (L.)

Strains of the codling moth resistant to DDT appeared in some British Columbia and Ontario orchards in 1957. Sevin, Guthion and diazinon have given excellent control of the resistant strain.

In laboratory experiments on the feasibility of controlling the codling moth by releasing sterile males, almost complete and permanent sterility was achieved without affecting normal behaviour by exposing male pupae to 40,000 rads of gamma radiation. Mating of a normal female with a fertile male before or after mating with a sterilised male resulted in fertile eggs.

Apple Maggot—*Rhagoletis pomonella* (Walsh)

In recent years the apple maggot became more troublesome in the Maritime Provinces than formerly, even when the recommended sprays of arsenate of lead were applied. The addition of lures to the spray did not increase its effectiveness. Several of the new insecticides were highly effective against the adults in the laboratory, but in orchards the results were less promising. A major project on ecology, behaviour and control of this pest was begun.

Aphids

Aphids of tree fruits can generally be controlled with a single application of an organic phosphate. The apple aphid, *Aphis pomi* DeG., is an exception and, because it recolonizes readily, can be readily controlled only by a persistent insecticide. Sevin and dimethoate are noteworthy because their toxic effects against the Aphid persist for several weeks.

Orchard Mites

Strains of the European red mite, *P. ulmi*, and of the two-spotted spider mite, *Tetranychus telarius* (L.), resistant to parathion, malathion, and ovex have developed in most orchards where these miticides have been used for a few years. Of 13 organophosphate miticides tested in Ontario against the parathion-resistant strain of *P. ulmi*, Trithion, Delnav, ethion, demeton, Guthion and Phosdrin gave good control; malathion, dimethoate and Ekatin M gave moderate control; and phosphamidon, TEPP and parathion were ineffective. Populations of *P. ulmi* and *T. telarius* resistant to ovex were readily controlled by Kelthane. Fenson applied at the pink-bud stage of tree development has satisfactorily controlled *P. ulmi* and *Bryobia arborea* H. and A. since 1957 in British Columbia.

Between 1954 and 1959, 30 miticides were evaluated in the greenhouse, and 18 of them in peach, plum and apple orchards. Of these, Mitox, Elimite, Genite 923, Kelthane, Guthion and Phosdrin were recommended for use in Ontario and have given good control of mites.

Intensive studies showed that *T. telarius* became more abundant than *P. ulmi* on peach seedlings in the greenhouse or screenhouses, apparently as a result of its gregarious habits, its more rapid development, its ability to fare better on damaged foliage and its webbing on the foliage. However, in young orchards the *P. ulmi* became more abundant. The reasons for this have not yet been determined.

Blueberry Insects

Studies in New Brunswick showed that two species of thrips, *Frankliniella vaccinii* Morgan and *Taeniothrips vaccinophilus* Hood, may cause sufficient damage to the low-bush blueberry during the first year of growth after burning, to cause crop failure in the following year. The life histories and ecologies of the two insects are similar. One application of dieldrin dust, made when the plants were beginning to send up new shoots in the spring after the burn, gave satisfactory control of the thrips.

Strawberry Insects

In British Columbia, the root weevils *Brachyrhinus ovatus* (L.), *B. sulcatus* (F.) and *B. rugosostriatus* (Goeze) were controlled for three seasons by a single application of aldrin, dieldrin or heptachlor incorporated into the upper six inches of soil before planting. The native root weevils *Sciopithes obscurus* Horn, *Nemocestes incomptus* (Horn) and *Nemocestes* species, probably *montanus* Van Dyke, were not controlled by these insecticides and became abundant in some plantings. Satisfactory controls have not yet been devised for these weevils.

Cane Fruit Insects

Among the most important pests of cane fruits in the coastal areas of British Columbia were the raspberry root borer, *Bembecia marginata* (Harr.) and the leafhoppers *Ribautiana tenerrima* (H.S.), *Edwardsiana rosae* (L.), and *Macropsis fuscula* (Zett.).

Comprehensive studies of the life-histories and habits of these insects were conducted and several insecticides were evaluated for their control. Outstanding control of the raspberry root borer was obtained with a drench of Diazinon applied in early April. A drench of the systemic dimethoate controlled not only the borers but also the three species of leafhoppers.

STORED PRODUCT INSECTS

Highlights from work on insects affecting stored products include initiation of ecological studies, improvements in control measures for various grain and flour pests, and appearance of a new pest, *Trogoderma parabile* Beal, in western Canada.

Infestations of insects, mites and moulds continued to cause losses of stored grains, especially in the Prairie Provinces, where grain has to be stored, often for several months, in farm granaries and emergency storages before it is sold. Infestations have flourished, especially in the lower grades of grain, in barns, farm-machinery buildings and improperly constructed outdoor cribs. Insects and mites that commonly occurred were *Cryptolestes ferrugineus* Steph., *Lathridius minutus* (L.), *Tribolium castaneum* (Hbst.), *Tribolium confusum* Duv., *Pyralis farinalis* (L.), *Oryzaephilus surinamensis* (L.), *Liposcelis divinatorius* (Mull.), *Acarus siro* L., *Glycyphagus destructor* Schr. and *Cheyletus eruditis* Schr.

Surveys of empty granaries showed that stored grain insects and mites occur in floor and wall cracks. The grain mite was found in all granaries sampled. Six-ounce jars of water placed at the surface of stored grain proved useful for detecting *C. ferrugineus*, *Lathridius* spp. and *Ahasverus advena* (Waltl.) but not Psocids or mites.

Hot Spots in Grain

Ecological studies showed that *C. ferrugineus* Steph. is often found in grain that is heating, and is usually accompanied by the mites *A. siro*, *G. destructor*, and *C. eruditis* and the fungi *Aspergillus flavus* Link, *A. glaucus* Link, *A. fumigatus* Link and *Penicillium malani* Thom. Heating occurs mainly during the winter in storages that contain more than 3,000 bushels. Temperature differences between the centre and the periphery cause moisture to move to the surface layers, where it condenses and forms favourable conditions for development of infestations. However, insects may also cause grain to heat near the centres or bottoms of grain bulks.

Confused Flour Beetle—*Tribolium confusum* Duv.

In flour mills, monthly spot fumigations of milling machinery is replacing semi-annual or annual space fumigations. A mixture of ethylene dibromide and carbon tetrachloride (usually 1: 7 by volume) is commonly used. Pyrethrum sprays are generally used on floors and walls and on outside surfaces of milling machinery. Pyrethrins-piperonyl butoxide (1: 10) mixed with surplus mill stock in elevator boots prevented infestations of *T. confusum* for five weeks after treatment.

Adult females were more susceptible than males to low doses (2 mg. per litre or less) of ethylene dibromide. Surviving females laid fewer eggs than untreated females but their progeny developed normally. Hatchability of treated eggs decreased with increased fumigant concentration, but hatchable eggs developed normally. Pupae eight days old were more susceptible than those one or two days old.

A New Warehouse Pest—*Trogoderma parabile* Beal

Severe infestations of this insect have been found in warehouses and flour mills in Alberta and Saskatchewan since 1957. At 32° C. the life cycle on crushed wheat required 57 days. At 32° C., egg production and adult mortality were high; at 20° C., many eggs were laid but none hatched; at 10° C., no eggs were laid. The requirement of a relatively high temperature for hatching indicates that reproduction is limited to the warmest period of the summer in western Canada.

Food Preferences

When given a choice of 12 milled cereal products *Tribolium confusum*, *T. castaneum* and *Cryptolestes pusillus* (Schonh.) were usually found in foods with a high content of wheat germ. Larvae of *Tenebrio molitor* L. preferred foods low in fat. Larvae of *Tenebroides mauritanicus* (L.) had no apparent food preferences among those tested.

Spider Beetles

Ptinus villiger (Reit.) was the most important insect pest of warehouses containing bagged flour and feeds. It also occurred sporadically at the surface of stored grain but damage was confined to small patches where the larvae fed. Infestations in flour packed in finely woven, sized, or dyed cotton bags were only about 10 per cent. of those in coarsely woven bags. The infestations were kept in check during the egg-laying period, April to August, by spraying the floors and walls early in April with 5 per cent. DDT or 5 per cent. methoxychlor, or by spraying every sixth week with 1 per cent. lindane or 0·25 per cent. pyrethrins–2·5 per cent. piperonyl butoxide, or every fourth week with 3 per cent. malathion.

Insecticides

Malathion applied at 2 p.p.m. to wheat of 13·5 per cent. moisture content gave 99 per cent. mortality of adults of *Cryptolestes ferrugineus* eight months later; 16 p.p.m. were required to give similar mortality at 15·5 per cent. moisture content. Oviposition in treated wheat with a moisture content of 13·3 per cent. was negligible. The baking quality of flour milled from wheat treated with 4 and with 8 p.p.m. of malathion was not affected adversely and no foreign odour was detected during baking or in cut loaves.

Silica aerogel with an average particle size of 3·0 microns caused 95 per cent. mortality of *C. ferrugineus* in three hours at 40 per cent. R.H. and in 6·1 hours at 85 per cent R.H. at 25° C. When the silica aerogel was impregnated with ammonium silicofluoride to give 3 per cent. fluorine (w/w), the exposure time required for 95 per cent. mortality was almost halved.

Fumigants

The fumigants used against insects in stored grain are mixtures of two or more of the following ingredients: ethylene dibromide, ethylene dichloride, carbon tetrachloride, propylene dichloride, carbon disulphide and chloropicrin. Dosages range from three to six gallons per 1,000 bushels; the fumigant is usually applied evenly over the grain surface. A stirrup-pump is often used to apply fumigant to infested grain in a 1,000-bushel granary, and a power-operated gear pump to treat 5,000 bushels or more in flat storages. Hand-powered or motor-powered equipment facilitates application from the outside of storages and so reduces the hazard to the operator.

Evidence that tough and damp wheat acts as a chromatographic column for some fumigants and that carbon tetrachloride acts as an eluting agent was obtained. Detailed investigation of the action of mixtures of fumigants in grain showed that gases differ in their rate of movement through grain and that the movements are affected by various physical factors.

INSECTS AFFECTING MAN AND ANIMALS

The more important developments in veterinary and medical entomology were: testing and introduction of systemic insecticides for control of cattle grubs and lice; discovery of means of mating warble flies and of rearing black flies from eggs to adults in the laboratory; elucidation of swarming behaviour of biting flies and its significance; and increased attention to studies of the cause of tick paralysis.

Biting Flies

Studies on bionomics of biting flies dealt mainly with mating behaviour, feeding and reproduction. Studies on swarming in *Culicoides* and in *Aëdes* showed that the swarm forms at a visually determined assembly point and that in the swarm a short-range, auditory response of the male leads directly to mating. Certain species of these genera mate on the ground on accidental contact; however, most of these species are local in distribution though excessively abundant and, fortunately, also do not require a blood meal.

The loss of the blood-sucking habit was demonstrated in one species of mosquito, in a number of black flies and in at least six species of *Culicoides*. In both midges and black flies species were found that suck blood in later life but do not feed in relation to the first ovarian cycle. In the *Prosimulium hirtipes* Fries complex, which has recently been shown to consist of a number of closely related species, the several siblings differ in feeding habits in relation to reproduction.

The feeding habits of mosquitoes and black flies were studied in detail by means of precipitin tests on the stomach contents. Many Canadian species of *Aëdes* feed on a wide variety of mammalian hosts, but usually choose the larger species. The mosquito *Mansonia perturbans* (Wlk.) feeds mainly on birds, and a number of black flies are probably restricted to birds.

The genus *Leptoconops* was recorded from Canada for the first time, from the Prairie

Provinces and British Columbia. Many new species of black flies were discovered and described in co-operative studies in systematics, cytogenetics and ecology.

A standardised source of heat and moisture was a satisfactory experimental stimulus for initiating probing activity by *Aëdes aegypti* (L.). Introduction of carbon dioxide into the cage increased probing activity and, in the absence of a human observer, was a prerequisite for initiating host-seeking behaviour. Probing activity followed a cyclical pattern, peak activity occurring every fourth day.

Investigations in southern Alberta showed that in irrigated districts about 95 per cent. of the mosquitoes develop in low-lying pastures and haylands where poorly designed irrigation systems and improper farming practices allow seepage and retention of irrigation water. The fungus *Coleomomyces psorophorae* Couch was found in the irrigated areas and in 1959 infected 12 per cent. of the larvae of *Culiseta inornata* (Williston). It may prove to be a useful natural control agent.

Equations were developed from laboratory and field ecological studies to forecast mosquito development in a region on the basis of meteorological and biological data.

The ecology, behaviour and control of black flies in the pulpwood cutting areas of eastern Canada, where they are serious pests, were studied from 1954 to 1956. Effective methods of controlling black fly larvae and adults by aerial spraying were developed. Black-fly repellents were assessed.

Of the 25 species of black flies known to occur in southern areas of the Prairie Provinces, nine were found in irrigation canals in Saskatchewan and Alberta. The canals are evidently re-infested each year by gravid females flying from permanent streams.

An oil solution of DDT is regularly used to control infestations of *Simulium arcticum* Mall. in the Saskatchewan River. The larvae are killed by ingesting naturally occurring suspended clay particles to which the DDT adheres.

Equipment and methods were developed by which eight species of black flies were reared from eggs or first-instar larvae to adults. Larvae were reared to maturity entirely on bacteria (*Bacillus subtilis*); this indicates that sewage in rivers may increase the severity of outbreaks.

Colonies of the horn fly, *Siphona irritans* (L.), were reared continuously on cattle in the laboratory as a result of the finding that exposure of the adults to 20 hours of light daily and temperatures over 70° F. prevent diapause in the pupa; immature stages are reared at 25° C. Flies that fed on calves did not produce eggs.

Thirteen named species, two subspecies and some unnamed species of *Culicoides* were found in British Columbia. Of these, *C. variipennis* (Coq.) is a vector of " blue-tongue " of sheep not yet known in Canada although present in the north-western United States. Others are serious pests of cattle and still others, *e.g.*, *C. obsoletus* (Meig.), are highly annoying to man. Some overwinter as larvae in mud, pupate and emerge in early summer, and live as adults until frost. Others appear to have two or more broods per year.

Warble Flies—*Hypoderma lineatum* (De Vill.) **and** *H. bovis* (L.)

The mating behaviour of the warble flies *Hypoderma lineatum* and *H. bovis* was elucidated. This allowed warble-free animals to be infested artificially with known numbers of eggs to measure survival of the grubs in the hosts. Resistance to warble infestation increases after hypodermal infestations, independent of age of the host.

Serological techniques were developed to measure production of antibodies by cattle infested with *Hypoderma* spp. Yearling cattle, previously uninfested, showed no titre of antibody immediately after infestation with *H. lineatum* and *H. bovis*, but a titre was obtained two months after infestation and within eight months it rose to a peak and then declined. In previously infested animals a titre was recorded at the time of the experimental infestation; it declined slightly until the fifth month and then rose to a peak at eight months. These techniques may be used to detect prehypodermic infestations.

Effectiveness of control measures was increased from 70–85 per cent. with two applications of rotenone to 85–95 per cent. with the systemic organophosphorous insecticides ronnel and Co-Ral. Since ecological studies showed that survival of the flies must be less than five per cent for suppression or eradication, systemics hold more promise than rotenone for satisfactory control in large areas. Moreover, they destroy prehypodermal stages of the grubs, preventing " licked beef " or extensive damage to the hide. Control measures, including spray concentrations, surfactants, spray pressures, coverage, dosage and timing of applications were evaluated. Injections of dimethoate and of antigens prepared from first-instar larvae showed promise against *H. bovis*. The effects of ronnel, Co-Ral, dimethoate and Sevin on circulating cholinesterases and the general health of cattle were studied, as well as the synergistic toxicity of ronnel and larval toxins.

In Ontario, rotenone sprays or washes, and a limited use of systemic insecticides maintained the substantial reduction in infestations of *H. bovis* in areas where cattle grub control is compulsory.

Oesophageal larvae of the common cattle grub, *H. lineatum*, were maintained in the laboratory in aseptic beef serum with added antibiotic for up to 30 days, and an average of 21 days. Observations indicated that larval respiration is aerobic and that oxygen is obtained by diffusion through the cuticle. Tissue damage produced by the first-instar larvae during migration and by later instars in the backs of the host animals was described.

Sheep Blowfly—*Phaenicia sericata* (Meig.)

The sheep blowfly was first recorded as a problem in Canada in 1953, on Bell Island, Newfoundland. By 1958, the fly was widely distributed throughout the province. The flies are also troublesome elsewhere in eastern Canada. Satisfactory control of infestations was achieved with an arsenical or lindane dip or by jetting with arsenicals, lindane or DDT. Jetting with dieldrin, although highly effective, was not recommended because of residues.

Musca autumnalis DeG.

M. autumnalis, the " face fly," was first recorded in North America in 1952, in Nova Scotia. By 1959, it was widely distributed in eastern Canada, and was an annoying pest of cattle and other livestock because of its habit of lighting on and crawling over the face of the animals. No control is known.

Cattle Lice

Studies on cycling in numbers of lice on cattle showed that certain animals are susceptible to lice and that lack of resistance in the host results in rapid increases in numbers of lice, especially in severe weather and at low levels of host nutrition. Uncontrolled infestations of lice cause secondary anaemia in the host that may lead to abortion in pregnant cows, and to death.

In cattle herds treated with systemic insecticides for warble control, lice were eliminated or reduced to sub-economic levels. Systemics, when administered internally, may be safely applied during cold weather when sprays may not.

Ticks—chiefly *Dermacentor andersoni* Stiles

BHC continues to be the most effective acaricide for protecting cattle from the Rocky Mountain wood tick. A spray applied along the heads and necks of animals when they are turned into infested pastures in early April kills nearly all ticks that are picked up during the tick season.

Physiological studies on tick paralysis were concentrated on the Rocky Mountain wood tick in British Columbia, where it has caused more cases of paralysis in man and livestock than has any tick elsewhere in the world. Studies on the feeding mechanism of the tick and on host susceptibility revealed hitherto unknown secretions by the tick during attachment and feeding. The marmot, found to be susceptible to the paralysis, was used in physiological studies of the disease.

The ear tick, *Otobius megnini* (Dugès), which is indigenous to deer and Rocky Mountain sheep in British Columbia, infested cattle and caused at least a dozen deaths of these animals.

3. FOREST ENTOMOLOGY

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Although there has been a substantial re-organization of research activities in the Department of Agriculture, as described in Part I, the structure of the Forest Biology Division is essentially the same as outlined in the 1948–1953 review. The number of workers engaged in forest entomology at regional laboratories and Divisional Headquarters at Ottawa comprised, in 1959, 105 research officers, 74 technician assistants, 71 forest biology rangers, 50 clerical assistants, and 103 seasonal employees (students and labourers). New laboratories have been constructed at Corner Brook and Quebec, a wing has been added to the laboratory at Sault Ste. Marie, and new accommodation for forest entomology is being provided in an addition to the Agriculture Research Laboratory at Winnipeg. The Chemical Control Section of the Forest Biology Division has been provided with improved research facilities in the K. W. Neatby Building in Ottawa.

FOREST INSECT SURVEY

The basic objectives, organizational structure, functions, and operating practices of the Forest Insect Survey have been described in a paper by B. M. McGugan, presented at the Tenth International Congress of Entomology. During the five-year period under review, there has been extensive collaboration with provincial forestry departments and the forest industry in infestation mapping, population assessment, and hazard rating in connection with major outbreaks where direct control measures were applied. The most important of these co-operative surveys were related to the control of the spruce budworm, *Choristoneura fumiferana* (Clem.), in New Brunswick and Quebec, and the black-headed budworm, *Acleris variana* (Fern.), in British Columbia.

Improved accessibility of the vast store of accumulated data, through the use of comprehensive coding systems and punch-card recording methods, has greatly facilitated the preparation of compilations on forest insects of Canada. To earlier published regional compilations of forest sawflies and Lepidoptera of Southern Ontario, there has been added the first volume of a national compilation of forest Lepidoptera; several succeeding volumes are in an advanced stage of preparation. A review of all biological control projects involving forest insects in Canada, undertaken by the Forest Biology Division in co-operation with the Entomology Research Institute for Biological Control, is nearing completion.

REVIEW OF SOME IMPORTANT FOREST INSECT PROBLEMS

The present review includes only new information on problems outlined in the 1948–1953 review, and introduces a number of problems that have assumed increasing importance in the last five years. For simplicity of presentation, certain basic studies carried out by the Forest Biology Division are included in Part I.

Balsam Woolly Aphid—*Adelges piceae* (Ratz.)

The balsam woolly aphid is more widely distributed in North America than was previously known. In the last few years infestations have been discovered on balsam fir in Newfoundland, on Fraser fir in North Carolina, and on alpine, amabilis, or grand fir in parts of Oregon, Washington, and British Columbia. In the latter province infestations occur in the coastal area north of Vancouver and near Victoria. In most of these regions the infestations have been present for many years, as evidenced by abnormalities in tree crowns and the annual rings. The evidence points to separate introductions of *Adelges* in these widely separated areas of North America, and rather limited regional spread. Although the Aphid occurs extensively throughout the Atlantic Provinces and the North-eastern States, it occupies but a very small fraction of the range of balsam fir. Intensive studies of the limitations imposed by summer and winter climate on distribution and abundance have been started in the Maritime Provinces.

The programme of predator introductions has been continued in co-operation with the Entomology Research Institute for Biological Control and the Commonwealth Institute of Biological Control. The search for promising predator species has been extended to India, Pakistan, Japan and Australia, whilst introductions have been continued from Europe. The release programme in North America has become a co-operative venture with the United States, the aim being to establish predators in all the known *Adelges* infestation areas. Shipments from abroad are received at Belleville, Ontario, where the release programme is co-ordinated by the Entomology Research Institute for Biological Control.

The most extensive liberations have been made in New Brunswick, where the following five European species have demonstrated their ability to withstand the winter climate and have spread varying distances from the liberation points: *Neoleucopis obscura* (Hal.), *Laricobius erichsonii* (Rosen.), *Pullus impexus* (Muls.), *Cremifania nigrocellulata* Cz. and *Aphidoletes thompsoni* Möhn. It is still uncertain whether more recently liberated species from India, Pakistan, Japan and Australia will become established. Among seven species liberated in Newfoundland, the following are known to be established: *N. obscura*, *L. erichsonii* and *P. impexus*.

All native and introduced species of predators appear incapable of effective maintenance on very light *Adelges* populations. *L. erichsonii* is capable, at somewhat higher *Adelges* populations, of reversing the normal build-up of the prey population in the summer generation. Introductions of additional species will continue.

Spruce Budworm—*Choristoneura fumiferana* (Clem.)

The information provided here is supplementary to the 1948–53 review and, as before, is confined to the spruce budworm problem in the eastern provinces. Investigations of the population dynamics of the budworm in New Brunswick demonstrate the importance of stand factors as an essential predisposing cause of outbreaks, whose incidence in time and place is determined by climatic cycles. They also indicate that certain parasites and predators respond to host density and may exert control in forest stands where budworm population increase is not too rapid or sustained. The population dynamics research has provided techniques and concepts that have proved useful in studies of the chemical control project against the budworm, while at the same time it has supported the view that control may ultimately be feasible through silvicultural or management methods.

Diseases of the spruce budworm have been investigated further. Three virus diseases of the spruce budworm have been distinguished by the characteristics of the infective particles and inclusion bodies, as well as by the tissues in which they develop: (a) a nuclear polyhedrosis affecting the tracheal matrix, fat, hypodermis and blood cells; (b) a granulosis (capsule) virus found in the cytoplasm of the same tissues; and (c) a polyhedrosis virus found in the cytoplasm of the mid-gut cells. The nuclear polyhedrosis and cytoplasmic polyhedrosis have not been found together in nature. Double infections of spruce budworm larvae by the nuclear polyhedrosis and the granulosis virus have been frequently noted, but not in the same cells. In laboratory experiments, the granulosis virus was less virulent than the nuclear polyhedrosis virus, and prior infection by either virus had an inhibitory effect on development of the other in the same insect. Double infections were more readily obtained when the granulosis virus was given an advantage in time of infection or number of infectious units. Total mortality was higher when the larvae were infected with both viruses. Small-scale field trials of the nuclear polyhedrosis and the granulosis viruses will be carried out in 1960.

A widely distributed microsporidian parasite, *Perezia fumiferanae*, causes mortality principally in the mid-larval instars, retards development, and reduces pupal size, adult longevity, and fecundity. Female moths developing from infected larvae transmit the disease to their progeny, and seasonal build-up results when healthy larvae feed on foliage contaminated by congenitally-infected individuals. The infection rate increased steadily in one budworm infestation in Ontario over a period of years, and was apparently an important factor in control.

Advances in the knowledge of crystalliferous, spore-forming bacteria of the genus *Bacillus* encourage belief that these organisms may prove useful in budworm control. Much basic work has been done on the toxic substance associated with the crystals, the onset of paralysis in insects after ingestion of the purified toxin or the crude spore-crystal mixture, and the internal changes accompanying external symptoms. The basic work was done largely with the silkworm and various native Lepidoptera. Recent laboratory trials indicate that spruce budworm larvae are susceptible to *Bacillus thuringiensis* preparations, with the characteristic cessation of feeding after a few hours and death after one or two days. Through the Bioferm Corporation of California, a sufficient quantity of a commercial preparation of *Bacillus thuringiensis* has been provided for field trials against the budworm in 1960. This will be a co-operative project of the Forest Biology Division, the Insect Pathology Research Institute and Forest Protection Limited. Tests of the same preparation with young salmon and small mammals will be carried out by the Fisheries Research Board and the Canadian Wildlife Service.

Aerial spraying to protect timber resources in New Brunswick was started in 1952, and continued each year to 1958. In the Gaspé Peninsula and the adjacent region of Quebec south of the St. Lawrence River, aerial spraying was carried out from 1954 to 1958. In New Brunswick, the gross acreage sprayed was 14 million acres, but substantial portions of the territory were sprayed two or more times during the seven-year programme; the net acreage protected by spraying was 6 million acres. In Quebec, the gross acreage sprayed was 3·8 million acres, but here there was less re-spraying during the five-year programme; the net acreage protected was 3·2 million acres. The policy throughout was to initiate spraying in any area, or to repeat treatment after an earlier spraying, only when cumulative injury to the trees and continued high budworm populations presaged imminent tree mortality. Except for 1952, when the emitted dosage was one pound of DDT per U.S. gal. of solvent per acre, the standard dosage throughout the operation was one half-pound of DDT per half-gal. solvent per acre. Populations started to decline in the Gaspé Peninsula in 1956, and in northern New Brunswick in 1957, and the decline continued into 1959 throughout all the infested areas except in central New Brunswick. The reduction to near-endemic numbers, occurring in areas that had never been sprayed as well as in those that had been treated, was due to a combination of factors including unfavourable weather, increased incidence of parasites and diseases and the DDT. No spraying was carried out in 1959 in the expectation that the remaining infestation in central New Brunswick would collapse. As events turned out, the 1959 season was favourable to rapid budworm development and high survival, and although parasites were not less abundant than in 1958, nevertheless populations built up during the year, necessitating spraying in 1960.

The effects of spraying in northern areas from 1952 to 1958 can be summarised briefly: (1) The majority of timber stands came through the outbreak without serious mortality, in contrast to the devastation of stands in unsprayed check areas or others that were sprayed too late in the outbreak cycle. (2) The preservation, by spraying, of foliage over some 9 million acres seems not to have prolonged the outbreak, for its duration was very similar to that of earlier outbreaks in New Brunswick, Quebec and Ontario, which ran their course without control measures, and terminated when vast quantities of balsam fir and spruce had been killed. (3) There has been no evidence that other destructive forest species have increased following spraying.

Unfortunately, the spraying adversely affected populations of young salmon and certain aquatic insects upon which they feed. As a consequence, an interdepartmental committee was set up to consider all resource interests and to support additional research on insecticide formulations, dosages and application techniques. Co-operative laboratory and field experiments by the Forest Biology Division and the Fisheries Research Board in 1958 and 1959 indicated that satisfactory budworm kill could be obtained with as little as one-quarter pound of DDT per acre, and that aquatic fauna would not be seriously affected at this dosage. The reduced dosage of one-quarter pound of DDT will be used in that portion of the 1960 spray project where there are important salmon streams; elsewhere the half-pound dosage rate will be employed. The total area to be sprayed in central New Brunswick is about 2·5 million acres.

Black-headed Budworm—*Acleris variana* (Fern.)

Outbreaks of this species occur periodically in balsam fir forests of Eastern Canada and western hemlock forests of British Columbia. Infestations do not usually persist longer than three or four years in a given area. Injury ranges from loss of wood increment to top-killing and tree mortality. Infestations are of particular concern in stands of western hemlock because of the risk of extensive top-killing.

Infestations in the northern part of Vancouver Island, noted in 1954, reached about one million acres in 1955 and about two million acres in 1956. Aerial spray trials in 1956 showed that the black-headed budworm could be controlled effectively with one-half to one gal. per acre of a 10 per cent. DDT-in-oil solution. Egg surveys in the fall of 1956 led to a forecast of substantial defoliation in 1957 on 155,000 acres that had already experienced two years of moderate to severe attack. This severely infested area was sprayed in 1957 at one pound of DDT per gal. per acre, and an additional 5,000 acres were sprayed at one-half pound per acre. Both dosages were effective, causing about 90 per cent. larval mortality. Grumman Avenger aircraft were used in this operation, the first time they had been employed for forest spraying in Canada. Considerable injury to young cohoe salmon, steelhead trout, and fish-food organisms resulted in a number of streams in the sprayed area. The infestation declined generally during the latter part of the larval period in 1957. Repetition of spraying in 1958 was unnecessary.

On the Queen Charlotte Islands, the most recent population increase started in 1958 and continued through 1959. In parts of the infested area, western hemlock stands had not recuperated from the effects of an infestation some years earlier. High hazard occurs on some 30,000 acres south of Skidegate Inlet, and plans have been made to spray this portion of the infestation in 1960. DDT will be applied at the reduced dosage of one-quarter pound per gal. of spray per acre to minimise the risk of injury to fish. Small experimental trials of a *Bacillus thuringiensis* preparation will also be carried out.

Lodgepole Needle Miner—*Recurvaria starki* Freeman

The needle-miner outbreak in the Rocky Mountain National Parks, which threatened extensive lodgepole pine stands in the 1940's and early 1950's, has steadily declined during recent years. The development of the outbreak is attributed to " climatic release," in the form of a series of winters with moderate temperatures during the coldest months, starting in the late 1930's and persisting until the late 1940's. Its decline coincided with the return of more severe winters, in which heavy mortality of the overwintering larvae commonly occurs. Although terminal and lateral shoot growth and radial increment were considerably reduced during the outbreak period, tree mortality was negligible and there was no significant increase in mountain pine beetle populations in the weakened trees.

Western Tent Caterpillar—*Malacosoma pluviale* (Dyar)

Investigations of the western tent caterpillar in British Columbia have been concentrated on intra-specific variation in behavioural characteristics, rate of development, and survival, and the influence of such variability on population changes. Differences in orientation capacity and rate of movement, feeding and development among larvae are reflected in colony behaviour and survival. Corresponding differences in adult activity influence the extent of dispersal and the intrinsic quality of the population at a given time and place. Increasing proportions of intrinsically weak individuals expose the population to hazards of a fluctuating environment (chiefly weather); hence inherent weakness appears to be as important as other biotic factors affecting population decline. The studies, which emphasise the importance of the quality of individuals making up the population as well as the mortality factors affecting it, are being continued through the range of yearly fluctuations in abundance.

Larch Sawfly—*Pristiphora erichsonii* (Htg.)

Infestations of the larch sawfly have persisted from Ontario to Alberta and new infestations have built up in Quebec and the Atlantic Provinces. Light populations occur on eastern larch in northern British Columbia, but the insect remains scarce on western larch in the southern part of the Province.

Tamarack is capable of withstanding repeated defoliation. Radial increment is almost complete for the season before sawfly feeding is at its peak, and denuded trees refoliate later in the summer. Continued defoliation in successive years reduces production of foliage and shoots and of increment throughout the entire bole; lower branches and scattered tips are killed first, and upper branches later. In recent severe and prolonged infestations, a small proportion of the trees have been killed. These have been chiefly trees in the intermediate and suppressed crown classes.

Sampling techniques for estimation of populations of the different life history stages of the larch sawfly, and determining the effect of various mortality factors, have been further refined. Life table data have been obtained in selected study plots in successive years. The larch sawfly in Central Canada retains its resistance to *Mesoleius tenthredinis* Morl., some 85 to 90 per cent. or more of the eggs of the parasite being encapsulated in the host larva. The sawfly populations in British Columbia and the Atlantic Provinces are still moderately to highly susceptible to *Mesoleius*, encapsulation of the eggs being correspondingly low. Evidence obtained in 1959 indicates that the origin of the *Mesoleius* stock may also be important in determining the host reaction. In experiments with sawfly larvae from Central Canada, only about 7 per cent. of the eggs of an Austrian strain of *Mesoleius* were encapsulated, whereas for eggs of various Canadian collections of *Mesoleius* the corresponding figure was 87 per cent. The search for parasites in Europe has resulted in collections of two additional species that will be tested in Canada, and European strains of *Mesoleius* will be studied further.

Continued investigations of small mammal predators have demonstrated the general superiority of shrews over mice as control agents and the usefulness of the cocoon-planting technique in estimating predation. In dissections of sample units of the moss layer of tamarack bogs, it was found that small mammal tunnels literally honeycomb the habitat of the sawfly cocoons, there being 30 to 40 linear feet of tunnel per cubic foot. Predation was highest among cocoons located within one inch of tunnels, and dropped to negligible proportions among cocoons three inches distant from a tunnel. In 1958, a colony of 22 *Sorex cinereus* shrews collected in northern New Brunswick was transferred to western Newfoundland, to add to the natural control complex in this Province which lacks shrews. During 1959, eleven of the released individuals and 119 progeny were recaptured in pit traps, indicating successful establishment and breeding at the release site. Studies of shrew dispersal and impact on larch sawfly populations in Newfoundland will be continued.

Swaine jack-pine Sawfly—*Neodiprion swainei* Midd.

This species occurs throughout much of the range of jack-pine in eastern North America, but serious infestations appear to be limited to eastern Ontario and western and central Quebec. In eastern Ontario, infestations typically occur in jack-pine stands on the rocky shore-lines of lakes; in Quebec, infestations occur commonly in extensive sand-plain stands where serious defoliation and mortality have resulted.

Intensive studies of the species have been in progress during the past five years. The sawfly overwinters as a prepupal larva within a cocoon in the ground; emergence of the adults is late and prolonged. This limits northward distribution of the species and seriously lowers survival of the larval population in unfavourable seasons. However, in regions where seasonal weather is generally favourable, the population is protected from the effects of an unusually short and cold season by persistence of a proportion of the overwintered prepupal larvae in diapause, adults emerging the second year after formation of the cocoon.

The eggs are deposited in a characteristic fashion in new foliage, the entire egg complement of a female typically being deposited in a well defined cluster in the needles of one shoot. The larger trees of a stand are favoured for oviposition and the eggs resulting and larval colonies are more numerous in the tops of the trees and at the ends of branches. Feeding occurs primarily on the one-year-old foliage. In heavy, prolonged infestations the remaining foliage may be limited virtually to that of the most recent growing season. The effect of defoliation on radial growth is more marked in young, vigorous, open-growing trees, but these are generally capable of recuperation. Growth reduction due to defoliation may scarcely be perceptible in old, dense, slow-growing stands; their recuperative capacities are much less, however, and serious mortality may occur in such stands.

Three species of small predacious mammals feed on the cocooned larvae, principally during the spring and summer months, but populations of mammalian predators have been very low in recent years. *N. swainei* is attacked by a complex of parasitic insects, whose habits and effects on population trends are being studied. Among pathogenic micro-organisms affecting the sawfly, a nuclear polyhedrosis virus has received most attention. First noted in north-eastern Ontario in 1953, and in the St. Maurice region of Quebec in 1956, the virus was propagated in extensive rearing experiments and employed in field trials in 1958 and 1959. The younger larvae are more susceptible and die more quickly from the polyhedrosis than older larvae. Many of the latter, though infected, survive and produce adults that transmit the disease to their progeny. There is also evidence that certain insect predators spread the disease among the population. Aerial spray trials with virus suspensions will be carried out in the Lake St. John region of Quebec in 1960.

Weevils Attacking Pine

The acreage of pine plantations in Southern Ontario has been greatly increased during the past fifteen years by plantings of Scots pine for the Christmas tree trade. These trees are cut at about six to eight years of age. Harvesting of a plantation may take place over a three-year period. This cycle of operations has led to considerable injury from weevils which breed in weakened or dying trees, stumps and roots. The northern pine weevil, *Pissodes approximatus* Hopk., breeds in the inner bark of stumps or in the stems of branches of decadent or dying pines. The pales weevil, *Hylobius pales* (Hbst.), breeds in the inner bark of roots and stumps below ground level. Neither of these weevils breeds in healthy trees, but the adults injure Christmas tree stock by feeding on the inner bark of stems and branches. This form of injury has become extensive after the first trees are removed from plantations, through the creation of extensive breeding sites in the form of stumps. Improved sanitation, through the prompt removal of decadent trees and debris, is one method of avoiding population build-up. Stumps could be rendered unsuitable for breeding during the harvesting period by cutting above the lowest whorl of living branches, thus keeping the stumps alive to the final harvest cutting. Alternatively, the stumps could be kept alive through the immediately following breeding season, and the remaining branches then removed in July or August, to allow the stumps to dry and become unsuitable before the second breeding season. These methods of control reduce saleable height of the harvested trees and require an additional operation in plantation management. Chemical treatment of the stump at harvest time in late fall is being investigated as a means of reducing the number of breeding sites. Adult weevils, which feed in the trees by night and return to the duff during the day, can be reduced by drenching the ground and the young trees with dieldrin at the rate of one part of 20 per cent. emulsifiable concentrate to 100 parts of water at 200 gallons per acre, at adult feeding time in mid-April and early August.

The pine root collar weevil, *Hylobius radicis* Buch., has also caused extensive injury to Scots pine and to intermixed red pine. This also is a native species with a wide distribution, but its presence is seldom detected in the absence of Scots or other exotic pines which are very susceptible to attack. The weevil breeds in the root collars of healthy trees, and is capable of killing trees up to four inches in diameter in three or four years. Larger trees are seldom completely girdled and killed, but the root collars may be seriously weakened and constricted. In heavily infested Scots pine plantations, many trees are killed before reaching Christmas tree size, and up to 95 per cent. before ten years of age. Satisfactory control can be effected by the application to the root collar and adjacent soil, of a drench of one part 25 per cent. lindane emulsifiable concentrate to 500 parts of water, at the rate of one pint per tree of Christmas tree size. One treatment provides protection for about four years.

Ambrosia Beetle—*Trypodendron lineatum* (Ol.)

Investigations on ambrosia beetles during recent years have been concentrated on *T. lineatum* (Ol.), which is the most abundant and destructive of five species encountered in logging operations in British Columbia. Great numbers overwinter in the forest litter in the margin of stands adjacent to logging operations. Concentrations occur in cool, moist sites near the bases of trees in a band up to 500 feet wide, the greatest densities occurring at 100 to 200 feet from the forest margin. The outer bark of standing living and dead trees is also a favoured hibernation site, concentrations near the ground level approximating those in the adjacent litter. The numbers under bark scales and in crevices drop off rapidly with height, but some hibernating beetles have been found 50 feet from the ground. Overwintering mortality is apparently low on Vancouver Island.

Massive flights occur early in the spring, when maximum daily temperatures exceed 60 degrees F. At this time the beetles are capable of sustained flight for one to several hours. Later, during active brood development, the beetles become flight-negative; this is correlated with temporary reduction of the flight muscles in both sexes and great increase of the ovaries in the female.

Spring attacks are concentrated in logs felled in October to December, but may occur lightly in fellings of January or later. Some of the overwintered beetles establish a second brood in mid-summer. This second attack of the season is much lighter than the spring attack. The young beetles of the first and second broods do not breed during the year of their development, but on emergence from the brood logs seek hibernation sites where they intermingle with survivors among the old beetles, which may constitute half or more of the hibernating population.

The severity of ambrosia beetle damage is gradually being reduced as a result of modern logging practices, namely, avoidance of large inventories of autumn-felled logs and prompter extraction of the logs from the felling site to water storage. Nevertheless, damage still occurs to susceptible logs in the woods at the time of spring flight and there is a continuing risk to logs in water storage. Small scale experiments have indicated that BHC sprays (0·4 per cent. gamma) will prevent attack. Newly established attacks can be curtailed by a mixed spray of BHC and 5 per cent. ethylene dibromide, the latter killing the beetles in the galleries and the former preventing additional entries. Attempts to prevent attack in felled-and-bucked timber on an operational scale by sprays applied from the ground or from helicopters have been largely unsuccessful. This is attributed to the impossibility of wetting the lower surfaces of the logs. Protection of logs in water storage is much simpler, and extensive spraying of valuable log booms by hand sprayers, pumps on rafts, and helicopters, has been carried out by several logging firms in recent years. Co-operative studies are being conducted by the British Columbia Loggers' Association and the Federal Fisheries Department to determine procedures in helicopter spraying of log booms that will reduce risk of injury to fish.

CEYLON

REVIEW OF ENTOMOLOGICAL WORK OF THE TEA RESEARCH INSTITUTE

By J. E. Cranham

Tea Research Institute, Talawakele, Ceylon

Entomology was re-established as a separate division of the Tea Research Institute in 1955, after eight years as part of the Pathology Division. A special entomologist was appointed also in 1955 for work on shot-hole borer, *Xyleborus fornicatus* Eichh., the most serious pest of tea in Ceylon. At the present time, the Entomology Division is staffed by three graduates (one engaged on further studies in the United Kingdom) and four technical assistants.

Shot-hole Borer

Xyleborus fornicatus (Scolytidae) is the only insect or mite pest of tea that causes extensive damage, being widely distributed at elevations between 1,000 and 4,000 feet. It is notable that badly-attacked fields may continue to give high yields, and a reduction in yield in the same pruning cycle is not yet proven. The long-term debilitation of the bushes and the increase of fungi causing wood rot after pruning are considered very serious.

Work by E. Judenko in the period 1955–60 has been concentrated upon the behaviour of adult beetles and upon chemical control, particularly with dieldrin. It has been shown that beetles outside the galleries spend a large part of their time on the lower branches. Treatment of the lower parts of tea bushes in plucking, with dosages as low as 1·3 lb. per acre (in dry conditions), have proved an effective control experimentally.

The use of dieldrin on an estate scale is complicated by possible side-effects on populations of tea tortrix, *Homona coffearia* (Nietn.). This tortricid was formerly a serious pest of Ceylon tea, but was controlled by the introduction of the braconid parasite *Macrocentrus homonae* Nixon from Java in 1935–6, which has since maintained an extremely efficient biological control. It was shown by Baptist (1955) that dieldrin sprays on tea after pruning could increase tortrix by upsetting the host-parasite relationship. This aspect, and the question of dieldrin residues in made tea, are receiving attention.

Mites

Four mite species are very widely distributed on Ceylon tea and locally cause serious damage. The yellow mite, *Hemitarsonemus latus* (Banks), directly damages the youngest leaves (flush) taken for crop. Scarlet mites, *Brevipalpus californicus* (Banks) and other species of *Brevipalpus*, and tea red spider mite, *Oligonychus coffeae* (Nietn.) damage the maintenance foliage and may cause defoliation and debilitation of the bushes. Purple mite, *Calacarus carinatus* (Green), also occurs on the maintenance foliage but is generally less damaging. Scarlet mites have received most attention, and population dynamics and control measures have been studied. Sulphur sprays and dusts control all four species, but when applied to tea in plucking, impart a taint to the made tea, so that the plucked leaf has to be thrown away for several weeks. Chlorobenzilate and Karathane have proved effective non-tainting acaricides for scarlet mites and red spider mite, but are not effective for yellow mite. Further work is in hand on chemical control, population studies, the effect of copper fungicide spraying on mite numbers, and on biological control (in collaboration with the Commonwealth Institute of Biological Control).

Nettle Grubs (*Limacodidae*)

Nettle Grubs are a serious pest in many estates in the Uva District, and less frequently in certain low and mid-country districts. The most common and injurious species is

Macroplectra (often cited as *Natada*) *nararia* (Moore). *Parasa lepida* (Cram.) and *Thosea recta* Hmps. are occasionally injurious, and several other species occur. Populations of *M. nararia* are often greatly reduced by a granulosis virus (wilt disease) in wet weather, and work has been carried out on the artificial spread of the virus by spraying a suspension prepared from diseased larvae. This has so far been proved effective on a small scale, but is less rapid in effect than DDT, from the use of which no side-effects have so far been observed.

Lygus Bug—*Lygus viridanus* (Motsch.)

This is a local pest damaging flush at elevations above 4,000 feet. A study of the biology and distribution has been carried out by D. Calnaido.

Other Pests

Other local pests of tea which have received attention during the period and are worthy of mention are as follows:—

White Grubs (scarabeid larvae) are injurious to young tea in nurseries and new plantings. The identification of larvae has not been worked out but *Anomala dussumieri* Blanch., *Microtrichia costata* (Wlk.) and *Leucopholis pinguis* Burm. are thought to be injurious species. Soil treatment with 2–3 lb. of aldrin per acre is normally effective.

Tea aphis *Toxoptera aurantii* (Boy.), is common on the new growth after pruning. Malathion sprays are effective.

Green bug *Coccus viridis* (Green) and brown bug *Saissetia coffeae* (Wlk.) are fairly common pests, normally kept under control by parasites (Aphelinidae and Encyrtidae). Work on chemical control has not yet proved effective.

Helopeltis theivora Waterh., is very locally a pest in Sabaragamawa. DDT sprays are effective.

Termite species which attack living wood include *Calotermes militaris* Desn. up country, and *Glyptotermes dilatatus* Bugnion and Popoff in low and mid-country. Injection of dieldrin into termite galleries in the branches after pruning has proved effective for control of *militaris* but is not practicable for *dilatatus*.

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EAST AFRICA HIGH COMMISSION

1. EAST AFRICAN AGRICULTURE AND FORESTRY RESEARCH ORGANIZATION

FOREST ENTOMOLOGY

Mr. J. C. M. Gardner continued as forest entomologist with this organisation until his retirement in 1957. During this period the programme of work initiated in 1950 was further pursued, and concentrated mainly on a survey of East African Forest Insects and the problem of *Oemida gahani* (Dist.).

With the help of the Commonwealth Institute of Entomology the formation of an authoritatively identified collection was continued most successfully, and duplicates were distributed to the territorial forest entomologists. The spirit collection of identified larvae and pupae was much enlarged. Considerable biological and ecological data were accumulated, and these together with details of the distribution of individual species were summarised in a publication by Gardner (1957).

Studies on *Oemida gahani* were continued, and the Kenya Forest Entomologist, S. J. Curry, participated in this work on the resignation of Forester J. O. Evans in March 1956. The taxonomy of the tribe Oemini was clarified with the help of E. A. J. Duffy of the Commonwealth Institute of Entomology, and the morphological and biological differences between *Oemida gahani* and its close relative *Androeme plagiata* Aur. were described. Records of the distribution of *O. gahani* proved that this species was much more widespread than was hitherto realised. It was found on the Uganda borders, northern, central and southern Tanganyika and records were received from entomologists in Southern Rhodesia and Natal. New host species were discovered particularly in the indigenous hardwoods of Kenya, and it was observed that although *Oemida* could infest logs and sawn wood of *Pinus*, living trees of this genus were, under normal condition, immune to infestation.

Seasonal fluctuations in populations of *Oemida* were correlated with rainfall. Peak emergences occurred in the rainy seasons. Attempts were made to estimate the incidence of the borer in softwood plantations from examinations of the cross-cut ends of the periodic thinnings, but this method proved unreliable. Some of the factors conducive to infestation were examined and the desirability of abolishing pruning, or alternatively developing protective treatments for pruning scars, was emphasised.

A full account of this later work was given by Gardner and Evans (1957).

1959–60

A lapse of almost two years occurred between Gardner's retirement and the arrival of his successors Tecwyn Jones and W. Wilkinson. This was most unfortunate as collections had continued to arrive from the three territories, and a large back-log of taxonomic and systematic work had accumulated. Efforts have been made to sort, classify and catalogue these outstanding collections but although 1600 identified duplicate specimens were given to the Kenya Forest Entomologist, little impression has yet been made on this large and ever increasing mass of material.

The appointment of two entomologists to the department has permitted a division of work into two convenient sub-sections.

Pests of Established Forests and Plantations (by Tecwyn Jones)

Preliminary surveys have been conducted in the three territories, and the relative priorities of the major insect problems have been assessed. It was apparent from visits, and discussions with Forestry personnel, that the programme of work for this section should concentrate on the problem of borers in living trees. These include *Oemida* and *Androeme* in Kenya and Tanganyika, the *Parinari* borer and ambrosia beetles in Uganda, and the recently discovered borer of *Isoberlinia* in Tanganyika.

The ecology and biology of these pests needs elucidation. Field investigations have barely started but laboratory work on the physiology of *Oemida* is in progress. The investigation of the feeding habits and minimum food requirements of the immature stages is an essential step in determining the factors affecting length of life cycle and fecundity. To facilitate these studies special techniques including the use of composite-wood breeding cells have been developed with varying degrees of success. A fruitful start has been made in studies of larval respiration rates and from them it is hoped to deduce rhythms of activity, the duration of each instar, and the onset and cessation of diapause.

One of the more urgent field problems is the development of a rapid and non-destructive method of sampling plantations. It is highly desirable to have an easy method of estimating the incidence of *Oemida* in a particular plantation and any changes which occur in the course of time. Various techniques including auditory, ultrasonic, radiographic and isotopic devices have been considered. As yet all of them have not been tried, but auditory methods seem unsuitable on account of extraneous interference, and radiographic methods are too expensive. Preliminary trials with ultrasonics were unsatisfactory because of the low output of the apparatus used and mechanical difficulties in coupling the transducers to the rough surface of the wood. The use of a very small radio-active source and scintillation counter seems highly promising and is being considered in conjunction with laboratories in the United Kingdom.

Pests of Nurseries and Young Plantations (by W. Wilkinson)

In some parts of East Africa termite attack on young living trees is an important obstacle to afforestation for which we have the least satisfactory remedies. It is a problem common to all three territories in varying degree, and successful control methods could have wide application in areas where the planting of trees has been retarded due to termite activity.

Records are now being kept with the object of collating information on the relative susceptibility of different trees to damage, the species of termite responsible, and the conditions under which attack takes place. Its concomitant function will be to allow prediction or probable termite danger in planting a new area, so enabling suitable precautions to be taken. Available data show no simple correlation of factors to explain attack, and it is clear that more evidence is needed, particularly as depredations may vary from year to year.

Control measures fall into two categories, destruction of the termites and protection of the trees by repellent barriers. Direct attack on many small underground nesting species is at present impracticable, but baiting methods are under consideration. Where the nest can be located various poisoning techniques are being tried out. Protection of young trees by mixing insecticides in the planting holes is an orthodox approach, but has the disadvantage of requiring careful application, and the effect is limited to the life of the insecticide and to its bounds of distribution. This method has been tried in several African countries. In Tanganyika, M. S. Parry has met with some success, and, in Uganda, K. W. Brown is co-operating in the present investigation. A method is sought which is effective, economically possible, and relatively foolproof in application. Two sites with different climatic conditions have been chosen initially, and trial plots of termite-susceptible *Eucalyptus saligna* and *E. paniculata* planted, under the protection of a " short " list of insecticides. In the next trials the amount of selected insecticides will be varied to find the effective minimum. Application of protective formulae is then envisaged on a larger scale under normal planting conditions at many sites throughout East Africa.

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2. A REVIEW OF ENTOMOLOGICAL RESEARCH CARRIED OUT BY EAST AFRICAN TRYPANOSOMIASIS RESEARCH ORGANIZATION

By J. M. B. Harley

In 1955 it was decided that the East African Tsetse and Trypanosomiasis Research and Reclamation Organization should undertake no further large-scale reclamation schemes in order to concentrate on research, and the title of the Organisation was correspondingly amended. In 1959, the tsetse research laboratory at Shinyanga in Tanganyika was closed down so that entomological research could be directed more towards epidemiological aspects of both human and animal trypanosomiasis and to improve co-ordination with other work on trypanosomiasis in progress at the newer laboratory near Tororo in Uganda. Shinyanga was the scene of Swynnerton's early experiments in tsetse reclamation, starting in 1923, and had been the headquarters of tsetse research in East Africa since 1930.

During most of the period under review there was a research staff of ten, a Chief Entomologist, seven entomologists and two botanists, working on entomological problems. Mainly during 1959, a reduction in staff occurred and at the end of that year a Chief Entomologist and two entomologists remained. It is likely that the establishment of entomological workers will remain at three in the foreseeable future.

In the preparation of this review of a wide range of work it has been necessary to report main conclusions very briefly; such treatment may convey a greater impression of certainty than is the case in the original paper so that specific points should be consulted in the original.

Relation to host animals

An important gap in our knowledge has been filled by the development by B. Weitz, of the Lister Institute of Preventive Medicine, of serological tests that enable the accurate identification of a high proportion of tsetse (*Glossina* spp.) blood meals. Many samples of blood meals of several species of East African tsetse have been examined by him and an account of some of these is given by Weitz and Glasgow (1956). For *Glossina morsitans* Westw., the species for which most evidence is available, warthog is the predominant host in most areas with percentages ranging between 16 and 55. *G. swynnertoni* Aust. also feeds mainly on warthog while *G. austeni* Newst. feeds largely on bushpig. Birds and reptiles are important hosts of *G. palpalis fuscipes* Newst., which also feeds on bovids. Bushbuck form the greater part of the food of *G. pallidipes* Aust. while a few feeds of *G. longipennis* Corti were all from rhinoceros.

Later collections of blood meals of *G. morsitans* emphasise the importance of warthog as a host in many areas but show that other mammals including kudu, buffalo and hippopotamus (Glasgow, *et al.*, 1958), and cattle (Pilson and Harley, 1959) may predominate in others. Glasgow *et al.* collected samples of active males, resting males and resting females of *G. swynnertoni* and found that the percentages of feeds on Suidae, mainly warthog, were respectively about 76, 80 and 90 per cent. The conclusion was that the previous results, based on samples of active males only, were broadly representative of the whole tsetse population. In the same area Suidae, again largely warthog, also provide over 90 per cent. of the feeds of both male and female resting *G. pallidipes*.

Isherwood, Duffy, Glasgow, Lee-Jones and Weitz (in preparation) show that bushbuck is the most important host of *G. pallidipes* in all three vegetation phases within an evergreen thicket mass, but there are differences in the proportion of bushbuck feeds, which also vary with season, between phases. Flies from an area of open thicket feed on a wider range of hosts, a result that was not unexpected as it is a transition zone between dense thicket and open grassland and probably has a fauna more abundant in species. In comparison the few specimens of *G. brevipalpis* Newst. caught in the same area made more use of Suidae.

The question of whether a particular host species is actually preferred by tsetse or whether it is merely more available, either because it is more numerous or because of its habits in relation to those of the fly, is an open one. Studies on this problem have been initiated by

Harley (1958a) and Johns and Hilton (1959) but further work is necessary before definite conclusions are reached.

Relation to temperature and humidity

A considerable effort has been directed towards ascertaining the effect of temperature and humidity on the physiology, ecology and behaviour of tsetse, in order to increase our understanding of the climatic requirements of the various species and of the factors limiting their distribution.

Temperature affects both the metabolic rate and the duration of development of tsetse pupae, the composite effect resulting in an optimum temperature in respect of the amount of fat necessary to complete development. Thus at about 22–24°C. depletion of fat reserves is minimal while fat consumption increases rapidly as temperature is raised or lowered (Bursell, in press, *Bull. ent. Res.*). Flies from puparia kept at the optimum temperature, therefore, emerge with greater reserves and it appears that, towards the lower end of the viable range of temperature, development is limited by the exhaustion of fat reserves. Smaller emerging individuals also have relatively less fat than larger ones.

During the puparial stage of *G. morsitans* water is lost by excretion through the spiracles and through the pupal membrane but the ability to regulate the loss due to the first two factors, together with extremely low membrane permeabilities, confers a high degree of resistance on puparia of this species which can complete their development at 10 per cent. relative humidity (Bursell, 1958a). Examination of puparia of other species shows that there is a close correlation between resistance to desiccation and the habitat in which they occur, suggesting that the water balance of the puparium may have been an important limiting factor in the invasion of more arid habitats from the ancestral hygrophytic type.

The corresponding study of the water balance of flies at rest (Bursell, 1959b) shows that, for the eight species studied, there is no correlation between resistance to desiccation and habitat, the conclusion being that the water balance of the adult tsetse has been no obstacle to the invasion of more arid habitats.

The rate of water loss of newly-emerged *G. morsitans* and *G. swynnertoni* released in the field in the habitat of *G. swynnertoni* is lower, except in the case of a single batch of recaptures, than the resting loss of flies maintained in the laboratory at the same mean temperature and humidity, even though the rate of fat consumption of the released flies shows that they were active for some of the time before recapture (Bursell, 1959b). This apparent anomaly suggests that wild flies may make use, during part of the time, of microclimates of high relative humidity, a possibility that requires further investigation in the field.

The thoracic spiracular filters are the sense organs responsible for an increase in activity of hungry flies in dry air, a reaction that increases in intensity with progressive decrease in humidity but which is abolished at low light intensities (Bursell, 1957a). It appears that this orthokinetic reaction with greater activity at lower humidities would tend to keep the insect moving until it comes to rest at a higher one. Thus this investigation also suggests that flies make use of microclimates of high humidity. Bursell points out that if a fly perched in a well-protected site, such as a crevice in the bark of a tree, the surrounding air might become more humid, due to normal water loss from the fly, which would in turn tend to inhibit activity and also result in a decrease in the rate of water loss. Investigations by Lamborn (1916) and Swynnerton (1921) showed that such resting sites are used, but more recent work in East Africa has not yet confirmed their findings although tsetse have been found to rest at night on leaves (see below), at the surface of which there must be a humidity gradient. On the other hand, in experiments where they have a choice of humidity, flies have shown a definite preference for the drier side of the chamber, a reaction that is governed by hygroreceptors in the antennal pits and on the surface of the flagellum (Johns, in preparation). Thus it appears that there are two opposing reactions to humidity.

Bursell (1957b) showed that the rate of water loss of unfed *G. morsitans* decreases during the course of desiccation. Also, that the rate of water loss of flies whose spiracles have been blocked, or of flies whose spiracles are kept open by exposure to carbon dioxide, increases linearly as relative humidity decreases. In normal flies, the curve is asymptotic, rates of loss in dry air being relatively low. He showed that this difference must be caused by spiracular control but was unable to identify the sense organs responsible for exercising this control.

Glasgow and Bursell (in preparation), continuing work started by Jackson (1953) and considering 13 years data on *G. swynnertoni*, confirm that flies are larger in the wet season and smaller in the dry. Fat reserves are also proportionately larger in the wet season, a probable cause of the seasonal variation in size. The correlation between size and the saturation deficit obtaining two months previously, first reported by Jackson, is also confirmed but these authors reject the simple causal interpretation as many other factors may also be involved and are likely to be at least as important. An unexplained progressive reduction in the size of the flies, amounting to about 10 per cent. by weight, has taken place between 1951 and 1958.

Bursell and Glasgow (1960) found by a comparison of the size and fat content of *G. palpalis fuscipes* that a lake-shore community was under stress as compared with a riverine one, in contrast to the results of a previous study in another area by Glasgow (1954), based on the analysis of fly-round catches. Comparison of available meteorological data suggests that differences in stress between different areas may be caused by differences in mean temperature. They also note that the percentage of non-teneral males caught on the party appears closely related to the nutritional status of the community but that the proportions of tenerals and female non-tenerals may not be.

The increase in the extent of the black abdominal banding of *G. pallidipes* with increasing humidity during pupal development discovered by Burtt (1954), was examined more precisely using an index of pigmentation (Bursell, 1960b). Monthly collections from the field showed that towards the end of the rains, in March and April, most unfed female *G. pallidipes* fell into the darker pigment categories. As the dry season advanced the distribution tended to become bimodal, with the darker mode remaining relatively steady while the pale one became progressively paler until October when it disappeared, after which the distribution was again unimodal. These changes could be accounted for on the supposition that breeding takes place partly in the riverine thicket (darker mode) and partly in the eluvial vegetation (paler mode), and that towards the end of the season the soil-space humidity of the eluvial zone reaches levels inimical to survival. This study therefore confirms conclusions from the study of water balance that desiccation during pupal development may be an important cause of death for species like *G. pallidipes* near the drier limits of their range.

Glasgow (in press, *Proc. R. ent. Soc. Lond.*) found that supernumerary stub veins occur in the wings of several species of *Glossina* and show a seasonal variation in incidence, becoming most common shortly after the hottest month. Some of the variations could be induced by subjecting puparia from the day after birth to high temperatures and if the effect could be calibrated it might be possible to infer the temperatures experienced in breeding sites. Welch (in press, *Proc. R. ent. Soc. Lond.*) reports similar variations in venation from wild *G. morsitans orientalis* Vanderplank.

The feeding habits of *G. swynnertoni* were examined by Glasgow (in preparation) and the interval between feeds found to vary from 1 to 15 or more days in males and from 1 to 8 days in females. The mean interval between feeds of males is longest in June, that is in the cool season after the end of the rains, and shortest in October at the end of the hot season. The data for females were few but it is interesting that the mean interval is shorter in April, during the rains, than in July, the former being significantly less than in males and the latter significantly more.

An estimate of the dorsal thoracic surface, as a measure of the size of the tsetse, is discussed by Bursell (1960a). Compared with wing-vein length a significantly better correlation was demonstrated with the residual dry weight of female *G. morsitans* from puparia maintained at 28°C. However, flies of a given weight vary in size according to the temperature experienced by the puparium so that puparia of a given weight produce smaller but relatively heavier flies at 30° than at 25°C. This limits the application of the theory that stresses acting on the pregnant fly may be gauged from the size of flies two months later, and Bursell suggests that where the mean temperature of puparial sites is likely to exceed 26°C., any inference should be based on puparial rather than adult size.

Other studies on morphology and physiology

Further studies were completed on the function of the choriothete and also on the milk gland of *Glossina*. A choriothete was also discovered in *Hippobosca* (Bursell and Jackson, 1957). Bursell (1955) has described the respiratory mechanism of the polypneustic lobes of the tsetse larva and also (1959a) the determination of the age of puparia by dissection.

At the time of emergence of *G. swynnertoni* from the puparium the wing musculature is incompletely developed, further development occurring only after a blood meal (Bursell, in preparation). This would appear to be an adaptation to viviparous reproduction by reducing the weight that must be carried by the female and also accounts for the characteristic increase in firmness of flies after the first blood meal.

Johns (in preparation) has examined in detail the structure and distribution of the rod-like and cone-like sensillae on the surface and in the pits in the flagella of *Glossina*. Previous work suggested that both types are hygroreceptive.

By measuring the oxygen consumption and water loss of flies during short bursts of tethered flight in the laboratory, Bursell (1959c) found that during flight the metabolic rate increases by a factor of 22, a somewhat smaller increase than is usual for insects. Water loss during flight is only six times the resting value and is therefore relatively low even at low humidity. Work has also been directed at elucidating what food reserves, other than fat, are present in *Glossina*. The only conclusion so far is that neither glycogen nor glucose occur in sufficient quantity to account for the non-fatty food reserves demonstrated in *G. swynnertoni* (Bursell, 1958b).

Sampling of tsetse populations.

Resting flies

Fly-rounds, the main sampling method, are known to give a biased sample of a tsetse population in that few replete males are caught and females, of which nearly all are hungry, are relatively rare. Isherwood (1957) succeeded in finding numbers of resting *G. swynnertoni* on the underside of branches of small trees. The female percentage in these samples was about 25 per cent., compared with 4·5 per cent. among catches of active flies in the same area, but is still lower than the expected figure for the true proportion of females in the population. Such catches yield a higher proportion of gorged flies of both sexes, an important finding in relation to the collection of numbers of blood meals for determination of the hosts utilised. Application of residual insecticide to the resting sites may also prove a valuable control method. Harley (in press, E.A.T.R.O. Annual Report for 1959, Nairobi) has shown that *G. morsitans* uses similar resting sites.

Isherwood and Duffy (1959) found that the distribution of resting *G. pallidipes* within an evergreen thicket area agreed with that of active flies caught on a fly-round but was quite different from that shown by trap catches.

Resting tsetse (*G. swynnertoni*) were first seen at night by Jewell (1958a), using ultra-violet light to locate flies marked with fluorescent paint. A few were seen resting only on leaves, an observation repeated by Isherwood and Duffy (1959 *l.c.*) who also found that *G. swynnertoni* left their daytime resting sites on the underside of branches at about sunset and returned to them at about sunrise. Subsequently Rennison *et al.* (1958) found that *G. pallidipes*, marked with reflective glass beads in a solution of gum acacia, could be located simply by the light from an electric torch and were resting on leaf surfaces. Southon (1959) used this technique on *G. swynnertoni* and located 90 marked and 37 unmarked flies of which all except three were resting on leaves of small trees between 1·5 and 10 feet from the ground.

Fly-rounds

Fly-rounds laid out according to the vegetation of the area have been used for a very long time in the study of *Glossina*. Ford, Glasgow, Johns and Welch (1959) describe a modification, which is now widely used, and termed a transect fly-round. This follows an arbitrary course along straight lines on compass bearings and is divided into short sections of equal length. Much more detailed information, particularly on the distribution of flies, can be collected by this method. Glasgow (in preparation) investigated the variability of fly-round catches and found, surprisingly, that in a comparison of day to day variation of catch of *G. swynnertoni* the transect fly-round is no better than the old type. The variance on the transect fly-round was greater than could be accounted for by random errors and must be due to changes in availability as the population would be unable to fluctuate so widely in so short a time.

Ford (1960) reports that flies may follow the catching party for some distance from a high density area before being caught, thus giving a misleading picture of the true distribution of tsetse on a fly-round. Welch (1960), when investigating the diurnal variation in catch of *G. morsitans orientalis*, showed that the first traverse of a fly-round, almost irrespective of the time of day, results in the highest catch. This confirms the results obtained by Jackson (1930) and should be taken into account when early morning peaks in activity are discovered.

Traps

Morris traps (Morris and Morris, 1949) have been used in the study of *G. pallidipes* and compared with other methods of sampling. Glasgow (1956) found that about 80 per cent. of the total catch in traps were females compared with 25 per cent. on a fly-round. Catching throughout the day revealed a marked peak in activity at 1400 or 1600 hours on the eastern edge of a large thicket mass but traps on the western edge showed an earlier peak.

Smith and Rennison (in preparation (a)) in another area compared the numbers of *G. pallidipes* caught in Morris traps, on cattle and on a fly-round. The fly-round appeared to give an unsatisfactory estimate of the population; fewer flies, but a higher proportion of females, were caught in traps than on cattle. The conclusion is that any estimate of the trypanosome risk to cattle should be calculated from the numbers of flies attracted to the beasts.

Catches throughout the day on cattle yielded greater numbers of flies of both sexes in the morning and evening, the evening peak being more marked in the wet season (Smith and Rennison, in preparation (b)). Fly-round catches of females were similar but those of males fell after a peak between 0930 and 1100 hours. Traps caught most females between 1230 and 1400 hours in both wet and dry seasons while males in traps showed a slightly later peak in the wet season and an earlier one in the dry, the latter being less marked. They suggest that the cattle catches of both sexes, and fly-round catches of females, may represent the hungry sections of the population while the trap catches of both sexes, and fly-round males, may represent active but non-hungry sections of the population.

The hunger stages of *G. pallidipes* caught by the same three methods were examined (Smith and Rennison, in preparation (c)) but there were considerable differences in hunger assessment between fly-boys and it was also considered that, in view of Bursell's work on sampling reported below, there was a possibility that hunger staging failed to indicate the nutritional status of the flies.

Rennison and Smith (in preparation) examined the effect of the frequency of emptying Morris traps and that of varying the width of the entrance slits of the cages. Provided the traps were carefully maintained and kept free from predators, these factors had no effects on the number of *G. pallidipes* caught.

Glasgow and Duffy (1958) used traps to assess the dispersal of *G. pallidipes* into open grassland. *G. pallidipes* penetrated open grassland with trees more freely than they did a rather open cleared area that had regenerated; they dispersed more freely into open country when the grass was long and were not constrained to follow paths in the grass.

Behaviour in relation to sampling

Flies sampled by four methods: standard catching party, resting catch, catch from a stationary bait ox and from a moving vehicle were examined and their fat content at a late stage of digestion determined (Bursell, in press, *Proc. R. ent. Soc. Lond.* (A)). This was low for the resting and bait catches, high for the standard catch and intermediate for the vehicle catch. The proportions of females showed the opposite trend. From these results it was deduced that there were four phases of behaviour in the male hunger cycle, (1) inactivity, (2) activity characterised by sexual appetitive behaviour, (3) activity characterised by appetitive behaviour in relation to the feeding reaction, but by indifference to the stimulus of moving objects and (4) as for (3) except that moving objects constitute an adequate stimulus for the release of the feeding reaction. This investigation shows that standard sampling methods do not provide a representative sample of flies in the late stages of the hunger cycle, a deficiency that must be borne in mind in assessing their implication. The results also bear on the problem of host selection by tsetse.

Control

Several trials of arboricides have been carried out, usually in collaboration with workers from other units, Fryer *et al.*, 1957; Ivens and Cochrane, 1956; Ivens, 1957; Pilson and Harley (1959). The arboricide 2,4,5,-trichlorophenoxyacetic acid will kill a number of woody plants and defoliate others for a period, but it has not so far proved possible to defoliate all species of trees in an area at the same time or to kill sufficient to render the woodland or thicket uninhabitable by tsetse. It seems that such treatment will be of greater practical value in controlling regeneration of felled bush and Glasgow and Duffy (1959) suggest that its application to cut evergreen thicket together with the planting of *Cynodon* sp., which smothers regeneration, might prove most effective.

A pilot scheme to find and apply a method of discriminative bush clearing to eradicate *G. morsitans* from wooded grassland with *Acacia* spp. in Ankole, Uganda, at first gave promising results. Later, an extension of the fly belt to cover at least three times the original area stretched resources to their limit and eradication was not achieved. A later experiment in part of the more recently occupied area showed that failure there could be ascribed to an inadequate technique; the fly was able to occupy another vegetation type which had not previously appeared to be of importance and which had not been treated (Harley and Pilson, in preparation).

A second pilot scheme at Mkata, Tanganyika, was successful in protecting cattle on the Veterinary Department's ranch in their wet season grazing area. This scheme involved a cleared barrier, selective clearing of savannah trees outside this barrier and sheer clearing of riverine forest, and was directed against four species of tsetse, *G. morsitans*, *G. brevipalpis*, *G. pallidipes* and *G. austeni* (E.A.T.R.O. Annual Reports for 1955–56 and 1956–57, Nairobi).

Bursell (1959c) was able to demonstrate differences in physiological state between samples of flies from cleared and uncleared areas associated with several discriminative clearing operations against *G. morsitans*, but the significance of these differences remains in doubt in view of uncertainties involved in sampling (Bursell, personal communication).

Morris (1958) studying the role of *G. pallidipes* in the epidemiology of sleeping sickness in the Busoga fly-belt found that in settled areas more flies could be caught in open fields than in banana plantations. Settlement also reduced the numbers of tsetse in an area and he suggests that planned settlement could prove a simple and permanent means of reclaiming land from this species of tsetse and of controlling *T. rhodesiense.*

Other studies

Methods for the estimation of population density have been compared by Johns (1958) and some biases reported. Southon (in preparation) estimated the population of *G. swynnertoni* in Block 9, Shinyanga, an area of about 40 square miles, using a large staff, concluding that there were 7,500 non-teneral males per square mile. Harley (1958b) showed that the availability of *G. morsitans* to a catching party in the wooded grassland of south-west Uganda was lower than in the miombo woodland of Tanganyika, a probable explanation of the frequent trypanosomiasis infections in cattle round the edges of the fly-belt where routine catches indicated that flies were rare. Jewell (1958b) estimated the population of *G. morsitans* in a 0·5 square mile isolated area, at three seasons, and searched for the number of puparia estimated to be present. The population was small and the fiducial limits wide, hence the conclusion that only a small proportion of the puparia present was found lacks an unequivocal foundation.

Southon (1959) studied predation on *G. swynnertoni* at various stages in its life cycle, noting many known and potential predators. He estimated that one species of spider, *Hersilia setifrons* Lawrence, might account for a daily mortality of 650 *G. swynnertoni* per square mile, that is, about 30 per cent. of the estimated total daily mortality.

The trypanosome infection rates of *G. pallidipes* and *G. palpalis fuscipes* in two different areas in the Busoga fly belt, along the north shore of Lake Victoria, were studied in detail. Some of the results are reported by Rennison (1956) and include the isolation of a strain of *T. rhodesiense* from *G. pallidipes*. Further results are given by Rennison and Wiggwah (1959).

The laboratory maintenance of tsetse in single tubes continued throughout the period under review until 1959 at Shinyanga and several improvements were made in technique. The investigation is now being continued at Tororo, the emphasis being on the efficient capture, transport and maintenance of wild females of *G. pallidipes* to start a laboratory colony. The effect of housing fairly large numbers of flies in relatively large cages, and a comparison of membrane feeding with feeding on sheep are under trial (Cockings, in press, E.A.T.R.O. Annual Report for 1959, Nairobi).

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3. REVIEW OF RESEARCH ON TICKS CARRIED OUT BY THE EAST AFRICAN VETERINARY RESEARCH ORGANIZATION

By J. B. Walker

The East African Veterinary Research Organization was established in January 1948, to undertake research on veterinary problems common to the four East African territories of Kenya, Tanganyika, Uganda and Zanzibar. It comprises a number of Divisions, one of these being the Division of Protozoal and Arthropod-borne Diseases, in which research on East Coast fever and related Theileriases of cattle and on Ixodid ticks is being carried out.

In the research on ticks which has been carried out so far priority has been given to studies on taxonomy, host preferences and distribution. Much of the work on tick distribution has been, and is being done by officers of the territorial Veterinary Departments. E.A.V.R.O. officers, however, have advised on the planning of surveys and assist with the identification of the more uncommon or atypical ticks. Very close co-operation is also maintained with officers of the territorial Game and Medical departments, with the Coryndon Museum, Nairobi, and with a number of workers outside East Africa, in particular Dr. G. Theiler of the Veterinary Research Laboratory, Onderstepoort, South Africa, and Dr. H. Hoogstraal of the United States Naval Medical Research Unit No. 3, Cairo, Egypt.

Taxonomy

Specimens sent in from the field are retained for future reference and taxonomic study and a comprehensive collection of East African ticks is gradually being accumulated. In addition, complete F_1 series of larvae, nymphae and adults of twenty-eight East African species of ticks have already been bred in the laboratory and kept for reference and comparison with field material. Such laboratory-bred series are invaluable. First, they make it possible to associate the immature stages correctly with the adults of each species and, secondly, they help to establish the range of morphological variation within the different species. Thus it becomes easier to identify field material and so accumulate accurate information regarding the host preferences and distribution of these parasites.

Special attention is being paid to the genus *Rhipicephalus* Koch. This is essentially an African genus and a number of species are of considerable importance as vectors of animal diseases. Complete series of the following species have been bred: *R. appendiculatus* Neumann, *R. evertsi evertsi* Neumann, *R. compositus* Neumann, *R. humeralis* Rondelli, *R. hurti* Wilson, *R. kochi* Dönitz, *R. maculatus* Neumann, *R. pravus* Dönitz, *R. pulchellus* (Gerst.), *R. reichenowi* Zumpt, *R. sanguineus sanguineus* (Latr.) and *R. simus simus* Koch. Similar laboratory-bred series of a number of other Rhipicephalids have been obtained from Dr. Theiler and a series of papers is planned giving comparative descriptions of all the available larvae and nymphae of species in this genus, together with information regarding their hosts, if known. These will, it is hoped, form the preliminary to a monograph on the genus.

Studies have also been made on a number of ticks belonging to the genus *Amblyomma* Koch and series of the following species have been bred successfully: *A. cohaerens* Dönitz, *A. eburneum* Gerstäcker, *A. gemma* Dönitz, *A. lepidum* Dönitz, *A. nuttalli* Dönitz, *A. sparsum* Neumann, *A. tholloni* Neumann and *A. variegatum* (F.). The immature stages of a number of these species have not as yet been described and descriptions will be prepared in due course.

Species of ticks which have been established in the laboratory are usually maintained, except those which parasitise almost exclusively reptiles or big game animals, such as, elephant or rhino; such ticks are often difficult to maintain in the absence of their normal hosts, and, in addition, are not likely to be of great economic importance. A number of the species listed above have been used in disease transmission experiments at Muguga and some have been supplied to other laboratories in Britain and the United States as well as East Africa, for experimental purposes.

Host Preferences and Distribution

Tick-borne diseases of domestic animals, for example East Coast fever, redwater and anaplasmosis of cattle and heartwater of ruminants, are of great economic importance in East Africa. Amongst other things, detailed and accurate information regarding the host preferences and distribution of the tick vectors of these diseases is essential before rational attempts can be made to control them. Ideally, carefully planned field surveys should be made to obtain these data. In practice, however, much of the information which we now have on this subject has accumulated from haphazard collections made by numerous different people. Such collections, valuable though they are, will never give such an accurate picture as a properly organised survey. Frequently, for example, little or no information is available concerning the hosts of larvae and nymphae even when those of the adults are known. Although this is partly due to the difficulty of identifying these stages accurately, it is also true that untrained collectors rarely find immature ticks. Special efforts will therefore be necessary to fill this particular gap in our knowledge.

Turning to the individual territories, many collections will have to be made in Uganda before the distribution of the various species of ticks known to occur there can be mapped in any detail.

In Kenya, on the other hand, a great deal of information on tick distribution has been accumulated over a period of about thirty years by E. A. Lewis, A. J. Wiley, S. G. Wilson and J. B. Walker. Much of this information, however, is still unpublished and it is planned to revise and sort all the available records and prepare them for publication.

Until recently comparatively little was known about tick distribution in Tanganyika but three members of the Veterinary Department, G. H. Yeoman, J. P. J. Ross and F. J. W. Hampshire, are now carrying out a broad survey designed to determine the species of ticks parasitising cattle in the territory. This will be of great value despite the fact that no collections will be made in the vast tsetse-infested areas from which cattle are virtually absent. In addition to this broad survey, very detailed collections and observations are being made, principally from livestock, in the Lake Province, especially the Mwanza and Kwimba districts, in the Arusha district of Northern Province and in the Iringa district of the Southern Highlands Province. The records obtained from all these surveys will be supplemented by records of miscellaneous collections from other animals and it is anticipated that, in a few years, a reasonable picture of tick distribution in the territory will be available.

In June–September, 1956, a scientific working party on tick-borne diseases and ectoparasites was organised jointly by the United States Naval Medical Research Unit No. 3, Cairo and E.A.V.R.O. It was attended by a number of eminent scientists from overseas, including Dr. H. Hoogstraal, who acted as co-ordinator of the group, Dr. G. Theiler, Mr. Glen M. Kohls of the Rocky Mountain Laboratory, Hamilton, Montana, U.S.A., and Dr. D. R. Arthur of King's College, London, and by officers from the local Veterinary Departments. The working party's activities in the field were concentrated in the Muguga area and in the vicinity of Tengeru, near Arusha in Tanganyika. Numerous collections of mammals and their ectoparasites were made and provided valuable new host and distribution records. When studies on the collections by the appropriate authorities have been completed a joint report will be issued.

FEDERATION OF MALAYA

RÉSUMÉ OF ENTOMOLOGICAL WORK

1. DEPARTMENT OF AGRICULTURE

By ENCHE AHMAD YUNUS

A brief review of work on the more important pests of Malayan crops undertaken during the period 1954–1959 is given below:—

Rice Stem-borers

Further progress was made in the investigations to control the rice stem-borer which is a serious pest of the crop in Malaya. Part of this work has been published (Wyatt, 1956; 1957) and two further papers will be going to the press shortly.

Four species of rice stem-borers occur in Malaya, the Pyralids *Chilotraea polychrysa* (Meyr.), *Chilo suppressalis* (Wlk.), *Schoenobius incertulas* (Wlk.) and the Noctuid *Sesamia inferens* (Wlk.). These species breed continuously throughout the year in the equable climate of Malaya and not in well-defined generations as in countries with pronounced seasons. This means that the rice crop in Malaya is exposed to attack throughout its life. Insecticidal treatment throughout the growing season is an obvious uneconomic proposition. The main hope of success against stem-borers in Malaya, therefore, lies in discovering the time at which the borers cause most damage to the crop and protecting it over that time.

Three randomised block pot experiments were set out to determine the effects of three insecticides (E.P.N. 300, endrin and dieldrin) and of different times of application on rice stem-borers. Some of the important conclusions from this work were as follows:—

(1) All three insecticides were about equally effective in reducing borer numbers but dieldrin is preferred on account of its low toxicity to man and other vertebrates.

(2) Time of application of insecticide was found to be of prime importance in bringing about borer control. A pronounced optimum time of application exists, which for the short-term variety, Pebifun, under conditions of the experiment was at six weeks after transplanting, and applications before and after this time are markedly less effective.

(3) It appears that the crop is most vulnerable to borer attack just before ear emergence, only tillers unbored at this time producing ears, while later attack only has the effect of producing white ears, usually by direct damage to the flowering stem.

In field investigations conducted in 1955/56, it was discovered that, during a season, borers can build up a severe infestation from a very small initial population in volunteer padi and that they appear to prefer the more fertile areas and particularly dense stands of rice or those in the shelter of bunds or trees, presumably because the ovipositing adults prefer positions sheltered from the wind.

A series of replicated field experiments in which an emulsion spray of DDT applied on various dates at the rate of 1 lb. active ingredient per acre confirmed that the plants were most vulnerable to attack just before flowering and that, although infested plants produced extra tillers, these did not appreciably reduce loss of yield.

In 1956–1958 experiments were laid out to determine whether or not results obtained earlier could be repeated in other seasons and in other places. Emulsion sprays of DDT and dieldrin at the rate of 1 lb. active ingredient per acre were used. Results from these experiments show that significant increases in yield resulting from one insecticidal spraying, *i.e.* applied at four weeks before first flowering (it is doubtful whether more frequent spraying would usually be economic) were obtained in only three out of 27 experiments. The conclusion was that at present it would be premature to recommend insecticidal treatment for general use in borer control. However, in another series of field experiments in which endrin was used as one of the insecticides, an effective control of the stem-borers and a significant increase in yield was obtained.

In 1958–1959 extensive studies of the bionomics of *C. polychrysa* and investigations into the control of the pest were carried out. It was found that BHC and Dipterex gave effective control of the pest at the following rates of application applied immediately after transplanting (Sept.–Oct.), BHC emulsion at 0·037 per cent. a.i. and Dipterex emulsion at 0·07 per cent. a.i.

With the co-operation of the Commonwealth Institute of Biological Control, twenty consignments of puparia of *Paratheresia claripalpis* van der Wulp were received from Trinidad. These were successfully reared on larvae of *C. polychrysa* and *C. suppressalis.* A total of 8,187 flies (representing 94 per cent. of those that emerged) was released in 1952 in a double cropping area of rice. Attempts to recover the parasite in 1952, 1953 and 1955 have unfortunately been unsuccessful.

Oryctes rhinoceros (L.)

The following experiments were conducted during 1954–1959 to control *O. rhinoceros* which is a serious pest of coconut in the country:—

(i) Insecticidal tests with 170 grubs of *O. rhinoceros* in containers holding 20 lb. of sawdust using 750 cc. fluid per treatment showed that in 9 days a kill of 70 per cent. was reached with aldrin at 1:20 v/v and dieldrin at 1:15 v/v, and 60 per cent. kill was obtained with dieldrin at 1:20 v/v and BHC (6.5 per cent. gamma) at 6 g./litre.

(ii) An *Oryctes* trap breeding-pit experiment was then carried out with the object of determining whether or not insecticide-treated breeding pits would prove to be attractive to *Oryctes.* Results show that the pits were attractive to the beetles as breeding sites but of the insecticides used (BHC at 0·5 per cent., 0·1 per cent. and 0·01 per cent. γ BHC and 0·5 per cent. Oleolindrine) only 0·5 per cent. BHC gave a high kill of 63 per cent. after 6 days.

Cremastopsyche pendula Joannis **on oil palms**

Two major outbreaks of this pest took place during the period under review in an estate of about 2,000 acres of oil palm. On both occasions, the outbreaks were successfully controlled by aerial spraying with endrin at the rate of 3·8 oz. per acre.

Helopeltis theobromae Miller **on cacao**

An experiment was completed to discover the most efficient and economic method of controlling *Helopeltis* attacking cacao. The insecticides used were as follows:—DDT, Gammalin 20 and Aldrex 2 by fogging at 10 fl. oz. a.i. per acre; and DDT and Gammalin 20 at 2 fl. oz. a.i. per acre and Gammalin 20, Dieldrex 15, Aldrex 2 and Endrex at 4 fl. oz. a.i. per acre by spraying. The insecticides were applied either twice or five times at fortnightly intervals.

Results show that there was a definite reduction in pest attack immediately after the first application of the insecticides and that they were almost equally effective in controlling the pest. Where five applications of the insecticides were made, the gap between the last application and the reappearance of attack was about 4–5 months, whereas with two applications the gap was about two months.

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2. FOREST RESEARCH INSTITUTE

The Entomology Branch came into existence in the early years after the last war. Until then, most problems that needed attention were investigated by Mr. F. G. Browne who concerned himself mainly with the biology of ambrosia beetles. He eventually established the Entomology Branch and was succeeded by Mr. K. D. Menon in the latter part of 1951. The Branch has been staffed throughout by only one Entomologist, except that in the latter part of 1955 an untrained assistant on daily rates of pay was recruited to assist the Entomologist in the collection and preservation of insects.

Several factors necessitated the establishment of a branch, though severely understaffed, to study entomological problems connected with trees and timber. Some of these factors were: the development of an export trade which emphasised the need to know the types of insects attacking export timber and the means of controlling them; the significant annual cost of replacement of insect-infested timber in wooden structures which in the case of Government buildings alone amounted to more than half a million dollars; and insect problems connected with growing of plants in the increasing numbers of nurseries, plantations and regenerated forest areas.

Prior to the period under review no special efforts were made to collect insects other than ambrosia beetles attacking freshly felled timber. By the end of 1959 there was a total collection of 3,474 individuals comprising various families of insects. Two thousand five hundred and sixty-eight individuals containing 914 species were identified. The food plants of 448 species are known. One thousand eight hundred and thirty-nine individuals were sent overseas for identification—mostly to the Commonwealth Institute of Entomology. Two hundred and sixty-three specimens were given away to foreign institutions, excluding several duplicates or preserved termites presented to the Colonial Termite Research Institute who have assisted in termite identification work. Three hundred and fifty insects (excluding numerous powder-post beetles reared for timber infestation tests) consisting of fifty-nine species were reared in the insectary. These included tree, timber and seed borers, and defoliators.

Insect damage and control of attack on trees

Numerous cases of insect attack on plants in nurseries, plantations and regenerated forest areas were investigated and recommendations for their control made. Defoliators were by far the most common though severe losses were inflicted by borers and termites. The long-standing problems of shot-hole borer, *Dendroplatypus impar* (Schedl), of *Shorea* spp. and the needle-hole borer (Lymexylidae) of *Dryobalanops aromatica* remain unsolved. A species of *Asphondylia* (Cecidomyiidae) suspected to be responsible for making branch and twig galls in *Dryobalanops aromatica* growing gregariously in eastern Malaya has been found to be amenable to control by admitting only a restricted amount of light to the young regeneration. Similarly, the mahogany shoot-borer, *Hypsipyla robusta* Moore, could be controlled by silvicultural means only. *Eurema hecabe contubernalis* (Moore) and *Semiothisa emersaria* (Wlk.), which completely defoliated 40 acres of *Albizzia falcata* during the dry months of February and March in two consecutive years, were prevented from doing any serious damage in the third year (1959) by a timely fogging of the plantation with a DDT emulsion. The longhorn beetle borer, *Hoplocerambyx spinicornis* Newm. rendered numerous trees of *Shorea resina-nigra* practically useless in various parts of the country. No practical means of controlling this species has yet been evolved. *Zeuzera coffeae* Nietn. proved to be troublesome borers of boles of young *Tectona grandis* planted in North Malaya. Termites attacked and killed, or seriously damaged, a number of plantation or regenerated trees, but numerous trees were saved by treatment with dieldrin. Benzene hexachloride was also used against termites but mainly in planting holes. Dieldrin was also used with marked success against shoot-boring ants, bark-eating caterpillars and some beetle defoliators. Lepidopterous defoliators were controlled by either benzene hexachloride or DDT.

Insect damage and control of attack on timber

Mr. Browne made a special study of ambrosia beetles since the pre-war years and is at present writing an account of the biology of more than 200 species of Malayan Scolytidae and Platypodidae. Prior to the period under review it was established that besides rapid extraction and conversion, ambrosia beetle attack on freshly felled timber can be controlled by the application of γ BHC immediately after felling. Subsequently more than a dozen types of proprietary insecticides were tested and some of these containing either BHC or endrin gave promising results. Experiments with more insecticides are continuing. The building boom in the post-war years, the developing export trade and the resultant fuller use of various species of timbers brought the problem of powder-post beetle attack on sapwoods (widely used in buildings, etc.) to the forefront. Investigations were carried out to discover the susceptibility of the various commercial species of timber to attack by the beetles and a list of the susceptibility of fifty timbers in the Malayan Grading Rules was published. A list of twenty-seven other timbers susceptible to attack was also compiled. Dieldrin, BHC and boric acid compounds have proved effective in the control of attack by the beetles.

Drywood termites have also drawn considerable attention, particularly during the period under review. A list of timbers susceptible to attack by these insects is being compiled. In the course of investigations the existence of two new species of termites in the Federation came to light; formerly it was believed that only one species existed in the Federation. Insecticides suitable for controlling powder-post beetles were also found suitable for the control of the drywood termites. Subterranean termite attacks on buildings have been effectively controlled by dieldrin applied as a soil insecticide in and around the foundations of buildings under construction. A soil fumigant known as " D-D Mixture " has been found very effective in killing active attack of these termites in infested buildings.

Data on the susceptibility of seasoned timbers to longhorn beetles and carpenter bees are being compiled. The bees have been found to attack almost any and every type of treated timber. Glossy oil type of paints have, however, proved to be one practical means of preventing attack.

During the period under review more than twenty articles on Malayan insects and their control have been published in various journals, chiefly the *Malayan Forester*, some of which have been reprinted as trade leaflets for the benefit of the numerous dealers in local timber.

3. RUBBER RESEARCH INSTITUTE

The entomological work of the Institute has been directed to the chemical control of the important pests of *Hevea brasiliensis* Muell. Arg. and of legume covers.

Termites

Coptotermes curvignathus Hlmgr. is a serious pest of rubber, attacking trees of all ages, eventually killing them. The chemicals used for its control for many years—mercuric chloride, calcium cyanide, sodium silicofluoride and white arsenic—though effective in driving them away from attacked trees, did not reduce the incidence of attack. Tests of a range of chlorinated hydrocarbons indicated that chlordane, aldrin and dieldrin are highly effective, giving the trees lasting protection against re-attack.

The persistence of these insecticides in soil has been investigated by bioassay, *C. curvignathus* workers being placed in contact with soil samples taken from around treated trees. To be about comparably persistent, the relative dosages of chlordane, aldrin and dieldrin need to be approximately 3:2:1.

The effect of soil type has been investigated. Six different soils have been treated with the same three insecticides and with endrin, samples afterwards being tested for insecticidal activity at intervals of one month. All four insecticides were rapidly inactivated in peat but a fourfold increase in dosage to some extent overcame the effect. Aldrin is superior to dieldrin in peat, while the reverse is the case in the other soils. Clay soil was the next to lose its toxicity, while the other four—volcanic, laterite, coarse sandy loam and fine sandy loam—retained the toxicity of aldrin and endrin for over two years and of dieldrin for over four years. Chlordane at equivalent dosage persisted only for three to five months in these soils (Newsam & Sripathi Rao, 1958). The cost of these insecticides at the very low rates of application needed is so small that it is feasible to treat every tree in an infested area, giving effective protection for a few years, the period depending on the soil type and the dosage applied.

Cockchafers

Severe outbreaks of grubs, which feed voraciously on the roots of rubber and legume covers, were frequent between 1930 and 1938, the principal pest being *Psilopholis vestita* Sharp. In recent years only a few localised outbreaks have occurred, mostly involving *Lachnosterna bidentata* (Burm.), which appears to be on the increase, young rubber in certain areas being infested year after year. Small outbreaks of *Leucopholis* spp. have also been met with occasionally.

Hand collection was for a long time the only method of control used. Recent laboratory tests and field experiments have proved that 0·1 per cent. aldrin or heptachlor, and 0·04 per cent. γ BHC, are efficient in killing the grubs, provided they are worked into the soil. The insecticide is poured onto the surface of soil loosened with a fork, or into a series of dibble holes made round the tree. On economic grounds, chemical treatment can be used only to protect the main roots of young trees, at least half a gallon of the diluted insecticide being required for each.

Mites

Dusting with sulphur has been replaced by spraying 0·05 per cent. dieldrin or 0·025 per cent. endrin emulsion against *Hemitarsonemus latus* (Banks) in nurseries. Other mites, including the predator mite *Typhlodromus newsami* Evans, are unaffected by these treatments, which are more efficient than sulphur in eradicating the pest.

Pests of legume covers

Tests with a number of insecticides have shown 0·25 per cent. DDT sprayed as an emulsion or wettable powder to give good results against the ladybird beetle *Epilachna indica* Muls., a serious pest of *Centrosema pubescens*. A 0·025 per cent. emulsion of endrin is preferred for treating the Pyraustid caterpillar *Nacoleia diemenalis* (Gn.), most important as a pest of *Pueraria phaseoloides*, though it also attacks other legumes planted as covers.

Reference

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4. INSTITUTE FOR MEDICAL RESEARCH

Up to 1953 the main effort of the Division of Entomology of this Institute was, in joint research with the Malaria and Filariasis Division, into the control of rural malaria with residual insecticides or drugs. The results were summarised and recommendations made on control policy (Edeson *et al.*, 1957). In 1953 the effort was switched to filariasis, and the branch laboratory which had been devoted to malaria was moved from Tampin in Negri Sembilan to Kuantan in Pahang, near to a large area of endemic filariasis on the Pahang River. As with malaria, the work on filariasis was partly supported by Colonial Development and Welfare Research funds.

Filariasis

A large amount of new information has been obtained about filariasis. The discovery in wild animals of a reservoir of the parasite, *Wuchereria malayi* Brug (Edeson and Wharton, 1958), apparently transmissible to humans, probably explains why house spraying with dieldrin has not produced any significant degree of control. Hopes for control rest mainly on the drug diethylcarbamazine (Wharton *et al.*, 1958; M. Yusef, 1959).

The biology of the main vectors (*Mansonia* spp.) has been studied in detail. The existence of two forms of *W. malayi*, adapted to different mosquitoes, has been demonstrated. The periodic form in the open settled rice fields of N.W. Malaya is transmitted largely by *Anopheles barbirostris* Wulp, in which it develops very readily. The chief vector of the semi-periodic form in the swamp forest areas is *Mansonia dives* (Schin.) (=*longipalpis* Wulp) which is an excellent host for this form. But *M. dives* is a poor host for the periodic form, while *A. barbirostris* is unsuitable as a host for the semi-periodic form (Wilson *et al.*, 1958).

In the same way there seem to be two strains of *W. bancrofti*, an urban one adapted to *Culex pipiens fatigans* Wied., and a rural one carried by a species close to *Anopheles letifer* Sandosham (Wharton, in press).

Insecticides

Trials of the residual insecticides in experimental huts against the mosquito vectors of malaria and filariasis were completed (Reid and Wharton, 1956; Wharton and Santa Maria, 1958). Trials of larvicides against *Culex p. fatigans* were made (Reid, 1956). Insecticide resistance in *C. p. fatigans* was investigated (Wharton, 1958), and susceptibility levels were measured in a number of other species of mosquitoes (Wharton, 1951). Resistance of bed-bugs to dieldrin and DDT is becoming common, but malathion is effective, and its residual life against mosquitoes is being investigated (Reid and Chee, 1959).

Aëdes aegypti (Linn.)

The distribution, biology and control of this mosquito were studied in relation to the risk of yellow fever reaching Asia (Macdonald, 1957a).

Systematics

Studies of the mosquito-borne viruses, such as Japanese encephalitis, have led to intensive work on the culicines, and to a long overdue revision of these mosquitoes in Malaya (Macdonald, 1957b). The work is proceeding in collaboration with the British Museum (Nat. Hist.) (Mattingly, 1959), the University of Malaya (Colless, 1959) and the United States Army Medical Research Unit working at this Institute. Studies on the systematics of difficult species groups of *Anopheles* have continued in collaboration with the University of Malaya (Colless, 1957). Four such groups are now known ('*umbrosus*,' '*hyrcanus*,' '*leucosphyrus*' and '*barbirostris*'), each containing some six or more species which are almost identical in appearance, but which differ in their biology so that though one or two species in each group are vectors of human malaria and filariasis, the rest are harmless.

Sand flies

Chance observation led to the discovery that several species of *Phlebotomus* are quite common in certain places, though they do not appear to bite man. These insects had rarely been collected before, and only two species were recorded from Malaya. Nine species have now been described (Lewis, 1957).

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FEDERATION OF NIGERIA

1. REVIEW OF ENTOMOLOGICAL WORK IN THE FEDERAL MINISTRY OF ECONOMIC DEVELOPMENT

Biology of Yam Beetles

Four species of dynastid beetles are known to attack yams in Nigeria, namely *Heteroligus meles* (Billb.), *Heteroligus appius* (Burm.), *Prionoryctes canaliculus* Arrow and *Prionoryctes rufopiceus* Arrow. The first of these is by far the most important and widespread, but the others may sometimes cause serious damage in some localities. Most of the investigation into biology and control of yam beetles has been concerned with *H. meles* and the following applies solely to that species.

The beetle attacks yams in the farms but must fly to the breeding areas on the banks of large rivers to lay eggs. Beetles of the next generation then fly back to the yam fields to feed. This has been studied using various light traps. The flight from the breeding area to the yam fields takes place in any one locality over a period of some three months, but the months when flying occurs vary from one locality of Nigeria to another. In the south, beetles begin to fly late in March or early in April and most have ceased by the end of June, although a few beetles may fly later than this. Further north, *e.g.*, Shendam near the River Benue, flying begins early in June and finishes about the middle of August. The number of beetles flying, as shown by the number taken at light traps, is not uniform throughout the flying period; several hundred may be taken on one night and none at all on others. This is governed largely by irregular rainfall, large numbers of beetles flying the day after heavy falls of rain. More beetles fly when rain follows a period of drought than if there are a number of falls of rain at short intervals.

Weekly sampling of yams in an observation plot at the West African Institute for Oil-palm Research near Benin showed that the beetles are attracted to yam plants only after the vine has appeared above soil level, and that the longer the vine and the heavier the weight of vine and foliage, the more likely are yams to be attacked. The percentage of yams planted on March 10, April 13, May 11 and June 11 which were attacked was 36, 21, 3 and 4 per cent. respectively. Thus, the earlier the planting the greater the attack rate, since the vines appear above the ground earlier and are exposed to beetle flight for a longer period. Yams planted in May and June escape attack because most of the beetles have finished flying by the time the vines appear above the ground (about one month after planting).

Entry into the soil usually takes place around the base and within about 6 in. of the vine although in areas where the vines are less well staked and where foliage covers a comparatively large area, the entry holes may be up to 2 ft. away from the base of the vine. There may be some movement of the beetles underground from one plant to another but this is not important; by far the greater number of yams are attacked by beetles entering the yam hills from above after flying. Beetles feed underground upon any part of the yam tuber which is in an edible condition, often attacking the yam sett first and then moving to the new tuber when it begins to form. The base of the yam vine is damaged only when many beetles are present on one yam and all the tuber has been consumed.

Beetles begin to leave the yam fields in mid-November to fly to the breeding areas. This takes place very quickly; all beetles left the fields at W.A.I.F.O.R. in 1958 about two weeks after the first beetle was observed flying to light. The return flight appears to be much less prolonged and the beetles are less attracted to light than in the flight to the yam fields; in 1958, 47 beetles were taken over a period of 19 days in the return flight in November as opposed to 899 in 85 days in April to June.

It is not certain where mating takes place. A number of females taken at light in November were put into jars to oviposit and 11 laid eggs before being put with a male; some eggs laid by seven of these eleven females hatched. Presumably therefore mating takes place either in the yam fields before flying or at light. The beetles which fly in

November contain about equal numbers of each sex, and males often die after mating in the laboratory, so that possibly pairing takes place when the beetles are attracted to light.

Eggs are laid in very restricted areas. So far larvae have only been found in the alluvial plains along the banks of large rivers in soils with a much higher clay and silt content than is normal in Nigerian soils. The number of eggs laid per female varies considerably, up to a maximum of 39 with an average of 28 eggs per female. Eggs weigh about 0·018 g. on first laying and gradually increase in weight through the absorption of water from the soil until they weigh about three times their original weight when they hatch 14–15 days later. Eggs were weighed regularly under different moisture conditions and it was found that even when exposed to fully saturated air the egg did not absorb water from the air. For normal development to take place the egg needs to be in contact with free water. This probably explains why the breeding areas are so restricted since few soils in Nigeria contain free water in mid-November.

Larvae in the first instar feed upon decaying vegetable matter, but during the second and third instars they turn to living plants and particularly to yams. Considerable damage is done in the breeding areas to yam setts every year by larvae of yam beetles.

Insecticidal Control of Yam Beetles

Since 1953, over 50 statistical trials and about 300 ' farmers ' trials have been done throughout the areas affected by yam beetle in an attempt to find improved methods of control. The methods tried have fallen into two main categories, application of insecticide at planting time and application to the surface of the soil after planting.

The only method that has given economic control of yam beetles to date is the application of insecticides to the yam sett before planting. Originally a 0·5 per cent. γ BHC dust was rubbed on to the surface of the yam and excess insecticide knocked off. This method decreased the number of damaged tubers at harvest by about 40 per cent. The percentage increase in yield varied inversely with the actual yield of yams but was usually between 10 and 20 per cent. with yields of 5000 lb. per acre upwards. The rate of application of insecticide varied considerably with the spacing and the type of yam sett planted but averaged about 30 lb. per acre. The increase in yield and the increase in value due to improved appearance gave good economic returns.

More recently a 2·5 per cent. aldrin dust has been used which reduces damage by about 70 per cent. and gives better increases of yield than the BHC dust previously used. Both these dusts are now being used by farmers and in the first two years about one and nine tons respectively of the two insecticides were sold.

Yam cultivation in Nigeria varies considerably from locality to locality and even in one locality according to the variety of yam grown. Planting dates in particular vary from November to June. Similarly, the time and duration of beetle flight varies from area to area as mentioned above. In areas where the beetle entering the yam hill finds an edible yam sett, then good control may be expected from seed dressings. Where the yams are planted earlier or the beetle flies later, so the yam sett is rotten when the beetle enters the yam hill, the insecticide has little effect upon damage. It was in an attempt to control attack under these circumstances that further methods were tried.

Application of 2·5 per cent. aldrin dusts to the planting holes has recently given good control of yam beetles in an area where yams are planted very early but the rates of application were comparatively heavy, about 156 lb. per acre.

Spraying various insecticides into the planting holes before planting has given some control but not so good as that given by dusting the setts.

A number of different insecticides applied to the surface of the soil at the beginning of the flying period have not given very useful results. Only one treatment controlled yam beetle damage and this used 151 gal. of spray per acre, which is much too high for use by farmers.

The Control of Cocoa Mirids

Low Volume Spraying with BHC

A trial was begun in 1955 to control Mirids on 100 acres of badly attacked mature cocoa trees. In the first year part of the plot was sprayed monthly from August to February with 4 oz. γ BHC in 5 gal. water per acre using power-operated, low-volume knapsack spraying machines. The other part of the plot received 6 oz. γ BHC. In the following two years, when it was obvious that the treatment had controlled Mirids, spraying was continued only in 5 one-acre plots to determine the rate of recovery of the trees when mirid damage ceased, and the increase in yield following the recovery. In 1957, only 4 applications of 4 oz. γ BHC per acre were given. Control of Mirids was excellent in both parts of the trial. No new damage was observed and any leaf blast observed was due to old mirid lesions. No difference was observed between trees sprayed at the two rates.

Scores for condition of the canopy were made on 100 trees in each of 5 one-acre plots at the beginning of the experiment and at yearly intervals thereafter. Considerable improvement in condition of the trees was observed following natural regeneration. There was a clear correlation between the condition of the trees and yield, and as the condition scores improved, so did the yield. In the second year, the overall yield was about twice that of the first year.

In 1957, tree condition continued to improve but was not reflected in the scores owing to a defect in the method of scoring. Yield was slightly less than in the previous year as cocoa yields were low throughout the Region in that year. This probably indicates that after the second year the trees have largely recovered from the effect of the Mirids and only natural improvement in condition and yield of trees can be expected thereafter.

Dusting with BHC

A similar trial was begun in 1955 upon 240 acres of mature cocoa trees with monthly applications of 20 lb. of 0·6 per cent γ BHC dust from power operated knapsack dusting machines from August to February in the first year. The plots were dusted 6 times in the second and four times in the third years. Good control was obtained using this dust but some damage was observed.

Again 100 plants from each of 5 plots of one acre were scored for tree condition and the yield recorded, and after the first year only these plots were dusted. Tree conditions improved considerably after the first year, though not quite so well as in the low volume spraying trial, and yields increased to about 1·8 times that of the previous year. In the third year tree condition improved slightly but was not shown in the scores and yield decreased to about 80 per cent. of the yield in the second year.

Spraying with hand-operated knapsack sprayers

This trial was begun to determine whether good control of Mirids could be obtained without the use of expensive powered spraying machines.

Two plots of 3 acres were separated by a belt of cocoa 45 yards wide. One was sprayed with 4 oz. γ BHC in 8 gal. of water per acre using hand-operated knapsack sprayers on 6 occasions between early September and the end of March. 100 trees were selected in each plot and scored for canopy and condition, and harvested every three weeks.

Good, though not perfect, control of Mirids was obtained and the number of pods harvested was greater on the treated than on the untreated plot, particularly after the first three months of spraying. Work on the trial ceased after one year so that no reliable data on yield increases following treatment are available.

Incorporation of BHC with fungicidal sprays

This experiment was designed to determine how well a mixture of γ BHC and Perenox, applied so as to control black pod only, would control Mirids on cocoa.

The " untreated " plot was sprayed with 2 oz. Perenox alone and the treated plot with 2 oz. Perenox and 4 oz. γ BHC, both in 3 gal. water using a hand-operated knapsack sprayer.

The spray applied as a target spray to pods alone reduced the Mirid population during the period of spraying but the reductions were not so great as those effected by applying the same amount of insecticide to the canopy.

Comparison of Coppicing with Spraying

An experiment was laid down in 1955 to compare the economics of regeneration of mature cocoa from mirid damage by spraying and by coppicing. A plot of 9 acres was divided into two and one half was coppiced. Both plots were kept free from mirid damage by spraying with BHC and DDT. A little mirid damage occurred before spraying began at the end of August 1956 but none was observed afterwards.

Tree canopy condition was assessed in July each year using a system of visual scoring and pods from the trees were harvested every three weeks. Tree condition of uncoppiced trees improved considerably after one year free from Mirids and the average yield increased with increasing canopy score. The yield of pods per tree in the second year was three times greater than in the first year. The regeneration of the coppiced plots proceeded well, and 25 trees bore a total of 71 pods during the 1957–58 season.

The experiment had to be abandoned prematurely after 3 years but by that time it was seen that by coppicing and spraying regularly to control Mirids, it was possible for trees to begin producing pods in the third year after coppicing. The coppiced trees, however, still had to be sprayed and at least three years crop had been lost. This experiment did not show results attractive enough to warrant recommending the expense of coppicing, and the loss of crop involved, even if they are very severely damaged by Mirids.

Sorghum midge

Since 1955 one entomologist has studied *Contarinia sorghicola* (Coq.) in Northern Nigeria where cultivated sorghums are the staple cereal crop. The severity of midge attack on main crop sorghums is largely determined by climate, which limits the potential breeding season, and by the degree to which the population increases on sorghums which flower before the main crop comes into bloom. The dry season is passed in a larval diapause and large numbers of diapausing larvae are carried from one season to the next in crop residues. On the basis of a survey, in which 167 localities throughout Northern Nigeria were sampled, it is estimated that in 1958 more than 4 per cent. of all sorghum spikelets were attacked by midge and £1,940,000 worth of grain was lost.

Cereal stem borers

The biology of the most important Lepidopterous stem borers of the major cereal crops has been studied and progress towards the accurate assessment of borer attack and of the resultant losses in yield has been made.

Above latitude 10° N., *Busseola fusca* (Fuller) and *Coniesta ignefusalis* (Hmps.) are most important, the former on cultivated sorghums (guineacorn) and the latter on millets. Both species pass the dry season in a larval diapause in stems and stubbles, and adults emerge early in the rains to oviposit on the crops during their first month of growth. At Samaru, Zaria, two generations mature during the growing season and the third generation enters diapause. Crop losses are greatest when many adults emerge from crop residues to oviposit on the young crop or when a second crop of millet is late-planted and is attacked by adults emerging from the first crop, but well grown guineacorn and millet tolerate considerable borer attack with little reduction of yield.

Further south where maize is more important and a longer growing season favours both the stem borers and their wild grass hosts the pattern is more complex. In addition to *B. fusca*, species of *Sesamia* (particularly *S. calamistis* Hmps.) and *Eldana saccharina* Wlk. may be locally dominant in guineacorn, millet and maize. Maize is far less tolerant of stem borer attack than either guineacorn or millet and in trials at Ibadan yield increases of 20–30 per cent. are obtained by chemical control of borers on the second maize crop.

Tobacco Whitefly

The biology of host selection in *Bemisia tabaci* (Genn.) was investigated. Results so far indicate peaks of visual sensitivity in the ultra-violet and yellow regions of the spectrum and also a poor olfactory sense. This was correlated with behaviour studies in the field employing yellow traps and a suction trap all operated at hourly intervals. There is evidence to suggest that the reaction of an individual white-fly to its two peaks of spectral sensitivity varies according to the time of the day. There is also circumstantial evidence that the physiological condition of the host-plant is as important as its botanical identity.

Field studies on the *Bemisia* transmitted leaf-curl disease of tobacco clearly indicate that he incidence of the malady is related to presence of old diseased tobacco plants, often ratoons, in or near new plantings. For some obscure reason farmers have a rooted objection to destroying these old plants and are quite happy to plant new fields of tobacco round them thus quite commonly achieving a 100 per cent. incidence of infection. In such cases one has only to glance around to find the old diseased ratoons with monotonous regularity. The ubiquitous composite weed *Vernonia* spp. which has been named a reservoir of the leaf curl virus on somewhat obscure evidence has in fact very little practical bearing on the problem.

Cola stem borer

The Cola stem borer, *Phosphorus virescens* var. *jansoni* Chevr. (Lamiidae) has recently been investigated. The life history is strictly seasonal. There is only one generation a year, the eggs being laid at the beginning of the dry season in the tips of the shoots. The combination of these facts seemed to call for a single strong application of a systemic insecticide at the height of the dry season so as to ensure maximum absorption and catch the young larvae while they are still in the highly translocatory first year growth. Small-scale field experiments on these lines gave promising results.

Coffee stem borer

Observations were made on another Lamiid, the Coffee stem borer *Bixadus sierracola* (White) both on *arabica* and *robusta* varieties. Attack was confined to badly kept and excessively shaded farms. Such conditions are all too common and are associated with mixed cultivations of coffee with cocoa, bananas, plantains, avocado, tung as well as shade trees.

2. REVIEW OF WORK BY THE MALARIA SERVICE OF THE FEDERAL MINISTRY OF HEALTH

By R. Elliott

Senior Entomologist

Work over the period has mainly been orientated to the possibility of developing a technique for malaria eradication using residual insecticides as house sprays in the rural area. A pilot project covering a population of 100,000 in Sokoto Province, Northern Nigeria, commenced in 1954 using three toxicants in separate areas: dieldrin, BHC and DDT. By mid-1955 the control of the *Anopheles* population at first achieved showed signs of breakdown in the dieldrin area; this was found to be due to the appearance and spread of a strain of the principal vector, *Anopheles gambiae* Giles, completely resistant to the cyclodiene insecticides, and effectively so to BHC (Elliott and Ramakrishna, 1956).

This led to a concentration of the resources of the Service on the resistance problem, and to the development of techniques for its investigation. An early advance was the introduction of a technique for the determination and measurement of resistance in the larvae of the small tropical *Anopheles* (Elliott, 1958) for which the standard techniques developed for temperate zone species were not entirely suitable. It was found that in several important species the resistance to insecticides of the larvae closely reflects that of the corresponding adults (Elliott, 1959a), and by means of tests conducted on larval populations of *A. gambiae* have been analysed into the homozygous resistant, heterozygous, and homozygous susceptible genotypes (Ramakrishna and Elliott, 1959). It has thus been possible to study the effects of different insecticidal regimes on the genetic composition of local populations, even in areas where adult mosquitos are so scarce as to be almost unobtainable (Elliott, 1959b).

The conclusion from this work is that there exists, from Sierra Leone to the Cameroons, an element in the local populations of *A. gambiae* possessing a genetically determined factor conferring resistance to the cyclodiene insecticides, BHC and toxaphene; this factor is inherited as a semi-dominant. Its effect on the use of these insecticides as antimalarial treatments is to turn an initial apparent success into failure as it comes to form the main element in the reduced population, which rises again to the level required for malaria transmission.

Over most of West Africa it will therefore be necessary to rely upon DDT, whose initial action is slower, and which may require reinforcement with other insecticides if the population is to be reduced below transmission level in an acceptable time. Laboratory and pilot scale field trials suggest that there may be some such possibility in a DDT/BHC mixture.

Other advances in the insecticide field include the development of the method for bio-assay of sprayed surfaces now adopted as standard by the WHO.

In the field of taxonomy additions to the mosquito fauna of West Africa have been recorded, including two species of *Aëdes*, two species and one variety of *Anopheles* (Service, 1958; 1959, a & b; 1960), and a form of *A. gambiae* combining the egg type of *A.g. melas* Theo. with the freshwater habitat and lack of salt tolerance of *A. g. gambiae* (Bruce-Chwatt and Service, 1957).

Self-perpetuating colonies of both *A. funestus* Giles and *A.g. melas* have been maintained in the laboratory for the first time (Service and Oguanah, 1958).

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FEDERATION OF RHODESIA AND NYASALAND

REVIEW OF WORK IN ECONOMIC ENTOMOLOGY

During the period under review the separate territories of Northern Rhodesia, Nyasaland and Southern Rhodesia have been joined politically and economically to form the Federation of Rhodesia and Nyasaland. The union is not complete, however, and entomologically the situation is rather complex. This review is concerned with the activities of the entomological sections of the Federal Ministry of Agriculture. These cover agricultural entomology in the two Rhodesias, tsetse fly entomology in Southern Rhodesia alone (see under Southern Rhodesia, p. 345), plant quarantine in the entire Federation, while the Cotton Pest Research Scheme is an independent Colonial Office scheme sponsored jointly by the Colonial Office, the Federal Government and the Nyasaland Government and so may perhaps best be considered here also. The entomological staff concerned with these activities have increased considerably since the last review covering the period 1948–54 was written. Agriculture and plant quarantine together now have the services of six entomologists and a separate post of helminthologist has recently been established; the Cotton Pest Research Scheme has an establishment of three entomologists and the Department of Tsetse and Trypanosomiasis Control and Reclamation, which now replaces the Tsetse Fly Operations Branch, has an establishment of a director and nine entomologists. In each of these divisions there are, at the time of writing, some vacancies, which reflects the shortage of qualified entomologists which seems to have been a constant problem since the war and one which is not merely a local problem but one which shows little sign of improving.

1. MINISTRY OF AGRICULTURE—RESEARCH AND INVESTIGATION

Agricultural Pests (by J. A. WHELLAN, *Chief Entomologist, Ministry of Agriculture*)

Army Worm

There has been no major outbreak of army worm, *Spodoptera* (formerly *Laphygma*) *exempta* (Wlk.) though one threatened towards the end of 1955 and subsequently the insect became widespread and, in some localities, caused severe damage. A very early report was investigated and proved to have been associated with a very localised freak hailstorm which occurred on 20th October. This brought on a flush of grass and larvae were found feeding on this, and on *Cyperus margaritaceus* Vahl, in large numbers early in November. Moths from these larvae were bred and emerged at the end of the month. Army worm moths were caught in the light trap maintained at the Salisbury Experiment Station on 18/19 and 19/20 October. These facts might confirm the supposition that emergence of the moths is stimulated by soil moisture, but could also indicate that parent moths move under the influence of meteorological conditions in a manner similar to locusts. Although the moths are mainly found in the wet season, besides these early emergences one was captured in the field in June and laid eggs from which the resultant larvae developed slowly but a moth was obtained at the end of August. Evidently then there is no true diapause but, depending on factors not fully understood but of which temperature and humidity seem likely to be the most important, moths may occur at any time of the year. Following the November emergence of moths the main occurrence of larvae commenced early in December. An unexplained feature of this in the Hartley area where about 400 acres of young maize was examined on the 1st December was that, although the maize had broken through the ground only on the 28th November and the ground was virtually weed free and surrounded by bare open country, almost every young maize plant examined had one or more, and sometimes as many as twenty, first instar army worm larvae on it. It would therefore seem that, as the minimum known incubation period for the eggs is three days, the eggs must have been laid and in very large numbers, before the maize or other grasses in the affected fields had appeared. It has previously been observed that army worm moths are not very particular where they lay their eggs, and the young larvae after hatching find their food plants, which are almost ubiquitous, generally without difficulty, sometimes by drifting with the wind on silken threads which they spin. This may have occurred in the instance under discussion though the distances would in some cases be rather great, a mile or more, unless the eggs had been laid on the ground, of which there is no direct evidence. It may be inferred from this that the moths do not need to be attracted by large quantities of grass, whether as crops or weeds. After this, and until mid-February, larvae in various stages of development were continually reported so that clearly there was a succession of overlapping broods which is in contrast to what has generally been observed previously, a series of two or three more or less clearly defined broods.

Maize ladybird

A large-scale outbreak of maize ladybird, *Epilachna hirta* (Thnb.), occurred in 1957 and much damage was done to developing maize. In subsequent years the pest has caused little damage and seems to have reverted to its previous role of a minor pest. Opportunity was taken, however, to work out its life-cycle and test various insecticides for its control under local conditions. It is now known that there are at least two generations annually and the probability is that the first, and perhaps often subsequent, generations complete their development on wild grasses and grass weeds. Both larvae and adults feed but the factors governing the transfer of their attentions to maize are unknown. In September 1958 large numbers of these ladybirds were found hibernating, despite day temperatures of 95° F. and over, in a small cave on top of a rocky hill in the Darwin District. This habit is, of course, well known amongst Coccinellidae in other parts of the world. On maize it was found that DDT did not give satisfactory control but that dieldrin, toxaphene and malathion did.

Stem borers

Further work on the bionomics of the maize stem borer, *Busseola fusca* (Fuller), has been carried out. In the course of this work a new species of *Busseola*, *B. phaia* Bowden, was discovered breeding in *Pennisetum purpureum*. This differs from *B. fusca*, not only in morphological features, but in its larval behaviour. Larvae of *B. fusca* enter a diapause early in the winter which is extremely difficult to break although there is some evidence that prolonged wetting will cause pupation, whereas although *B. phaia* also normally becomes quiescent over the same period, exposure to warm humid conditions, such as normally occur in spring, suffices to cause it to resume activity. In the last review larvae of *B. fusca* were reported as having been bred from *P. purpureum*. While strictly true, the inference that they had fed on this grass may be incorrect since it has been observed that before entering diapause the larvae are given to wandering and may enter any hole of suitable dimensions where they may then pass the winter.

Cutworms

Cutworms, the larvae of *Agrotis* spp., have remained troublesome on many crops, especially maize, and an attempt has been made to find out what it is that makes certain areas attractive to them, and to find an economical and reasonably reliable method of preventing their attacks. This work is incomplete. Of the many species of *Agrotis* known to occur in Rhodesia it appears that the commonest species is *A. segetum* (Schiff.) while the only other species found to behave in a similar way are *A. spinifera* (Hb.) and *A. longidentifera* (Hmps.). Whether or not ploughed-in green manures make land attractive to the moths or enable larvae to mature remains uncertain, but it is known that larvae of all sizes may be present through the winter, the numbers decreasing with time and, in the laboratory, feeding may take place at this time on vegetation buried beneath the soil surface. In irrigated land at this time feeding and development take place as in summer, though presumably at a slower rate. Insecticidal seed dressings showed little sign of promise and at present the best available control method seems to be the application of insecticides to the base of the plants in fields known to be susceptible to attack.

Maize rootworm

The maize rootworm, *Apophylia murina* Gerst. while remaining of infrequent occurrence in Southern Rhodesia is proving increasingly troublesome over most of the maize growing area of Northern Rhodesia. A survey made early in 1960 showed that it was present on most farms in the maize belt between Monze and Broken Hill. On some of them it had been known for thirty years and at times the attacks are so severe that some farmers reap no crop at all. It seems that aldrin applied above the planted seed will have most chance of effecting control but a full investigation of this problem is planned for the 1960–61 season.

White grubs

White grubs have over the last few years proved very troublesome in planted pastures in the Marandellas area. They eat off the roots of the grasses, mainly *Chloris gayana* (Kunth.) varieties, so completely that the sward, which by then is noticeably unthrifty, may be rolled up like a carpet. Observations were made on the biology of the beetles and an experiment was laid down to ascertain how effective would be an insecticide incorporated into the soil before planting. The larvae were found to belong mainly to *Eulepida mashona* Arr. The adults emerge in spring at the time of flush of most woodland trees, the foliage of several species of which form its principal food. There is one generation annually but most damage is done as the larvae are approaching full size, towards the end of the rainy season. In the insecticidal experiment dieldrin and DDT were chosen for trial because of their long residual effect. Dieldrin was found to be significantly superior to DDT and at 1 lb. per acre gave almost complete protection for the two years which have elapsed since application, and this protection is continuing into the third year.

Bean stem maggot

Following reports from East Africa, tests were carried out for the control of bean stem maggot, *Melanagromyza phaseoli* (Coq.), using insecticidal seed dressings. It was found that aldrin, endrin and dieldrin applied as emulsions at 0·2 per cent. by weight to the seeds gave almost complete protection. Germination was scarcely affected. There was some evidence that for best results the seeds should not be stored after treatment.

Pests of lucerne

An investigation was commenced on the insect complex associated with lucerne. As was expected the number of insects concerned was found to be large and varied and many of them were unknown previously to the entomologists in the branch and still await determination. One of these, a Jassid, at times causes severe damage, the leaves yellowing and eventually dropping. The pea aphid, *Macrosiphum pisum* (*Acyrthosiphum pisi*) (Kalt.) (Harris), at times causes severe damage, whereas in South Africa it appears to be of relatively little importance. Probably the most important injurious insect, however, is the clouded yellow butterfly, *Colias electo* (L.). This frequently builds up to very large numbers towards the end of the wet season, but the larvae are then commonly exterminated by a polyhedral virus disease. Some attempt has been made to evaluate the factors leading to the epidemicity of this disease, but so far without success.

Helopeltis

A study of *Helopeltis* was commenced but little progress was made. There is some doubt about the species concerned and whether more than one is involved.

Bush locusts

A study was made of the green, *Phymateus viridipes* Stål, and brown, *Maphyteus baccatus* (Stål), bush locusts. Failure to secure feeding by newly hatched nymphs made it impossible to follow the complete life-cycle of *P. viridipes*, but there is no doubt that this occupies two years, of which almost one is spent in the egg stage, hatching of the eggs occurring in the middle of the rainy season. This explains years of alternate rarity and abundance of this insect, although there is not a clear-cut alternation. This insect, when numerous, does severe damage to forest, fruit and ornamental trees. Reports which are considered reliable have been received of migratory swarms making sustained flights at considerable altitudes. As usually encountered, however, the insect is rather a feeble flier, seemingly relying on warning colours and distasteful odour and flavour for protection.

Pests of rosaceous fruits

Research into the pests of rosaceous fruits has been commenced, particular attention being paid to fruit flies, of which *Ceratitis capitata* (Wied.) the Mediterranean fruit fly, and *C.* (*Pterandrus*) *rosa* Karsch, the Natal fruit fly, seem the most important. Woolly apple aphis, *Eriosoma lanigerum* (Hsm.) seems to be a fairly recent introduction which may be increasing in importance. It is also intended to study fruit-piercing moths, but these are of very erratic occurrence and have hardly been noticed since the work started.

Pests of Stored Grain (by D. J. W. ROSE)

Khapra beetle, *Trogoderma granarium* Everts, was discovered for the first time in Southern Rhodesia early in 1955 in beans stored at Bulawayo. Before the end of the year this pest had been found in considerable numbers in most of the main grain storage centres in Northern and Southern Rhodesia. During 1956 the situation rapidly deteriorated and very heavy losses were suffered due to this pest alone.

At that time it was the practice to store most grain in bags in very large, tightly built stacks. It had been found previously that under these conditions serious insect losses were confined to the peripheral bags. The temperatures which developed in the centre of the stacks due to the activities of insect pests protected the bulk of the maize from further attack. This measure had some value in reducing losses due to the rice weevil, *Sitophilus* (*Calandra*) *oryzae* (L.) but it possibly created favourable conditions for the rapid build up of infestation by Khapra beetle after its introduction to Rhodesia. Khapra beetle thrived in the warm conditions in the centre of stacks. Temperatures as high as 40° C. developed and large quantities of maize were discoloured due to stack burn.

In 1957 a pest control programme was introduced to serve all central grain stores. This consisted of fumigation of stacks of grain with methyl bromide, application of residual insecticides to grain stacks and premises, and enforcement of good hygiene measures. Stacks of grain were fumigated under gas-proof sheets with a dosage of 3 lb. of methyl bromide per 1,000 cubic feet for a minimum period of 24 hours. The largest stack fumigated in this way contained 10,000 tons of maize.

More recently more attention has been given to investigation of the techniques employed. Gas sampling tubes have been built into a variety of commercial size stacks and measurements made of the distribution and concentration of methyl bromide during experimental fumigations. The speed of delivery of gas, size and shape of stacks, distribution channels and methods of sealing sheets at the base of stacks are among factors investigated. Once the data have been fully analysed the findings are expected to have wide practical application.

Insecticides are applied to stacks of grain as a routine immediately after fumigation and thereafter at one to two monthly intervals. Early investigations indicated that malathion was effective in killing exposed *Trogoderma* larvae. Mixtures of malathion and DDT have been generally applied in routine sprays since then. Present trials are designed to discover the best rate, formulation and interval of application to use under local conditions. Malathion applied as a wettable powder formulation at 100 mg./sq. ft. has given good residual action for one month applied to sacking under normal storage conditions. *S. oryzae* were used as test insects. Other trials have been made to evaluate dusting sacks layer by layer with 0·5 per cent. lindane dust at the rate of 1·5 oz. per bag as stacks are built. Preliminary results indicate that this measure gives some protection to the stack from moth infestation.

During the past two years moth infestation has been unusually severe in most grain depots in Northern and Southern Rhodesia. The species concerned have been *Ephestia cautella* (Wlk.) and *Plodia interpunctella* (Hb.). Unexpected widespread outbreaks occurred for the first time in January 1959. Heavy webbing developed on stacks and a considerable amount of grain required cleaning before sale. Weight loss due to moth infestation was surprisingly small. Residual sprays with malathion and DDT applied at heavy rates failed to achieve control, but sprays with Pybuthrin in risella oil applied at four-day intervals for six weeks were successful in controlling the infestation at one depot where this could be done. During the winter of 1959 the infestation was apparently brought under control by fumigation (May–July). However, in January 1960 similar widespread outbreaks have occurred and this problem has still to be solved.

General observations made during regular inspection of grain stores have clearly confirmed the importance of good hygiene in limiting reinfestation of fumigated grain. Reinfestation has been a more serious problem in depots which receive grain all the year round. To try to solve this problem trials have been made using polythene sheets to enclose stacks and give physical protection to them after fumigation. Two stacks in sheds have been covered in this way. Unfortunately in each case the trial had to be abandoned due to water condensing under the top sheet and spoiling sacks of grain.

The most satisfying result of the pest control programme has been the virtual disappearance of *T. granarium* from central grain stores. No infestation has been found during the last two years excepting in small traders' stores in Native Reserves where control measures have not been applied. Losses due to other pests have been very considerably reduced, but even excluding the moth problem, reinfestation by *Tribolium* spp. and to a lesser extent *S. oryzae* is sufficient to require refumigation of stacks of grain kept for more than six months. By maintaining these measures it is estimated that the overall weight losses during storage are now no more than 1 per cent. in comparison with 5–10 per cent. previously.

Another major aspect of investigation has been concerned with bulk storage of maize in silos. A large silo at Aspindale near Salisbury was opened for use in 1955. It was built to hold 50,000 tons of maize in 60 silo bins each fitted with a circulatory system for fumigation of the grain with methyl bromide. Initial fumigation failed and heavy insect infestations developed in bins causing serious losses due to heating and downgrading of maize through discoloration. Early investigations suggested that the failure of fumigation was due to structural faults in the silo. This has now been confirmed although finding and remedying all the faults has not yet been completed. Successful fumigations in repaired bins containing 900 tons of maize have been made with a dosage of 1 lb. of methyl bromide to 15 tons of maize for an exposure of 48 hours. A study is being made of the distribution of concentration of methyl bromide throughout the bulk of the grain during fumigation. Each bin is being examined individually.

Trials were made with an alternative fumigant known as Phostoxin for use in bins which could not be fumigated at that time with methyl bromide. Phostoxin tablets release phosphine when in contact with moisture in the grain. Tablets were added to the flow of grain on the conveyor belt at the time of filling the bins at the rate of ten tablets per ton. These trials were completely successful and more than 50,000 tons of maize have since been fumigated in this way as a routine. Fumigated grain has been stored in sealed bins for over a year and no evidence of insect infestation, heating or discoloration of the grain found.

Attention has also been given to measures for protecting grain for export. For two seasons, all maize for export was fumigated immediately before dispatch after loading into open railway trucks. The trucks were covered to the ground with gas-proof sheets and fumigated with methyl bromide at the rate of 15 lb. per truck, containing 40 tons maize, for 20 hours. Later investigation, during which gas concentrations were measured, revealed that this method was not successful during windy conditions and there were practical difficulties in obtaining a sufficiently reliable seal along the railway lines. Greater success has been obtained by building 1,000-ton stacks of maize for fumigation before railing to the port. Careful attention is given to spraying and cleaning of railway trucks, transit sheds at the port and ship holds.

2. COTTON PEST RESEARCH SCHEME (by J. P. TUNSTALL)

The Cotton Pest Research Scheme was established in 1956 with the object of developing methods for the control of cotton insect pests, particularly the Red Bollworm, *Diparopsis castanea* Hmps. and Cotton Stainers, *Dysdercus* spp., in the Federation of Rhodesia and Nyasaland. The Scheme is administered by the Department of Agriculture, Nyasaland.

The scope of the work and the cotton areas with which the Scheme is concerned have been previously described (Tunstall, Sweeney and Matthews, 1959; Sweeney 1960). The work on *Diparopsis* has been concentrated mainly at the Gatooma Research Station, Southern Rhodesia and that on *Dysdercus* at the Makanga Experiment Station, Nyasaland. On the basis of work carried out at both these places, investigations have been extended to other areas of the Federation, notably the Central and Southern Provinces of Nyasaland, the Sabi Valley area of Southern Rhodesia and to areas in Northern Rhodesia.

In the development of control measures, both chemical and otherwise, considerable importance has been attached to biological studies, particularly in regard to the behaviour of the insect on the cotton plant and other hosts.

Diparopsis castanea Hmps.

D. castanea is, generally, the most important of the cotton bollworms in the Federation, infesting the crop throughout the season. Studies of its biology have been mainly concerned with:—

- (i) a determination of the proportion of larvae forming diapause or overwintering pupae and the period over which these pupae give rise to moths during the following season;
- (ii) the behaviour of all stages of the life cycle in the field; and
- (iii) an assessment of natural mortality.

An account of the production of diapause pupae and the pattern of moth emergence in Nyasaland has been given by Pearson (1945). At Gatooma, the proportion of larvae forming diapause pupae increases from 0 per cent. in February to 100 per cent. in May. Subsequent moth emergence extends from September to March the following season with peak emergence in December and January. A small proportion of the pupae (approximately 2–8 per cent.) do not complete their development during the season following pupation.

Investigations into the effect of temperature on diapause pupae have shown that immediate development occurs on exposure of pupae to temperatures of 75° F. and 85° F. At 95° and above, there is considerable mortality, while at 65° F. or lower, development is suppressed.

The depth of pupation has been shown to affect the period of moth emergence from diapause pupae. With pupae artificially buried in August at depths of 6 and 8 inches emergence is virtually completed by December, whereas at depths of 0·5 and 1 inch emergence is considerably delayed. It is considered that this is due to temperature differences affecting pupal development. Under certain conditions, it may be possible to effect a measure of control through inversion of the top 8 inches of soil, thus reducing the effectiveness of the initial invasion of moths.

Continuous observations of all stages of the life cycle in the field have shown the periods over which the insect may be exposed to the action of insecticides. The extent to which larvae move over the plant or ground has been determined, and this information has been used in the design of bio-assay techniques. The length of the life cycle from egg to adult was shown to be approximately 10 weeks, and it is doubtful whether there are more than two effective generations produced in a season.

Considerable mortality occurs at all stages in the life cycle, much of which is due to ants removing eggs and attacking larvae on the plant and pupae in the soil. The ant *Pheidole megacephala* (F.) is of importance.

Carcelia evolans (Wied.), an important parasite of *Diparopsis* in Nigeria, is being studied with a view to its release in the Federation.

Dysdercus spp.

The work on *Dysdercus* at the Makanga Experiment Station has been reported in some detail (Sweeney, 1960).

Two species, namely *Dysdercus intermedius* Dist. and *D. fasciatus* Sign. are of primary importance, and several aspects of their biology, including host preference, have been studied in detail. *D. nigrofasciatus* Stål is relatively uncommon while *D. superstitiosus* (F.) is of no importance.

The main investigation has been the identification of the alternate hosts of *Dysdercus* and the determination of their relative importance in the Lower Shire River area of Nyasaland. The arboreal hosts are the most important, the major ones being *Sterculia africana*, *S. appendiculata*, *S. quinqueloba*, *Adansonia digitata*, *Ceiba pentandra* and *Thespesia garckeana* Herbaceous hosts are of little importance.

Sterculia africana is the most important pre-cotton host and is the main source of the initial infestation of the cotton crop in February and March. In certain areas, *S. quinqueloba* becomes of importance.

The eradication of *S. africana* offers a possible means of cotton stainer control, and to assess the effectiveness of such a measure, a circular area of 5 miles radius has been cleared of this tree in one of the main cotton-growing districts. A total of 4,000 trees were felled. However, owing to the general low level of *Dysdercus* populations in the Lower River over the last two years, it has not been possible to reach any definite conclusions.

Besides felling, the destruction of alternate host trees by ring barking and by chemical methods is being investigated.

Phonoctonus nigrofasciatus Stål is an important predator, but, under natural conditions, a limiting factor is the inability of the predator to distribute itself sufficiently rapidly in accordance with the movement of *Dysdercus* from host to host. The biology of *P. nigrofasciatus* has been studied in some detail, and, as it is possible to mass-rear the predator, the effect of controlled releases is being investigated.

A study of crop loss due to *Dysdercus* is being made, employing large field cages in which insect populations may be controlled. It is believed that from a consideration of the *Dysdercus* population on alternate hosts in November and December, it is now possible to predict years of severe cotton infestation.

Heliothis armigera (Hb.)

H. armigera is of considerable importance in certain areas of the Federation, particularly in the Central Province of Nyasaland and in the high veld areas of Southern Rhodesia. The main attack occurs during the flowering period of the cotton plant and follows the initial attack of *Diparopsis*. This double attack extends the period over which the crop must be protected with insecticides.

Pectinophora gossypiella (Saund.)

An outbreak of *P. gossypiella* in the Sabi Valley, which was detected in May 1959, presented the first record of this insect in Southern Rhodesia. Initial investigations indicate that there is an absence of larval diapause and that the insect over-winters on *Hibiscus dongolensis*.

Chemical control of cotton pests

The toxicity of a wide range of insecticides to the major cotton pests is being determined. Endrin, applied weekly, at the rate of 0·25 lb. active ingredient in 10 gallons of water per acre over a period of eight weeks from first buds, has given a fair measure of *Diparopsis* control. The treatment, however, has failed to control *Heliothis* effectively in some seasons, unless the period of spray applications was extended. DDT has been shown to be more effective than endrin in controlling *Heliothis*, although the reverse is true for *Diparopsis*. The relatively new insecticide Sevin has proved more toxic to *Diparopsis* than has endrin. Concentrations of this insecticide to give an LD50 with first-instar larvae were 0·0045 and 0·0152 per cent. respectively.

A major problem in the control of *Diparopsis*, and also of *Heliothis*, is the difficulty of obtaining an adequate spray coverage of the plant, especially in the later stages of growth. Various methods of application are, at present, being investigated, this work being carried out in collaboration with the Colonial Pesticides Unit at Arusha, Tanganyika.

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3. Tobacco Pests (by J. B. Legge)

The following is a brief review of the work and results at the Tobacco Research Board's Station at Kutsaga.

Cutworms and the Soil Pests

The biology and bionomics of three species of cutworms* and numerous soil-inhabiting beetle larvae† are being investigated in commercial crops, and in a rotation experiment designed to study the effects of two types of grass and a weed fallow in a tobacco rotation.

Previous work has established the relative economic importance of these pests; the cutworms were found to be responsible for about half the loss of stand attributable to insects which occurred in the immediate post-planting period, and these pests were active over the whole possible planting season (a period of about four months, October to January). Nearly all the remaining losses were attributable to coleopterous larvae, with the Tenebrionids being most injurious in the first half of the planting season and the whitegrubs in the latter half. Up to a third of the plants set out may be destroyed by these three classes of pests within two weeks of planting.

Good control of cutworms was obtained using 8 oz. of dieldrin per acre in 25 gallons of water applied over the plant and to the surface of the soil immediately surrounding it immediately after planting. The same amount of insecticide incorporated in the soil around the roots of the plants, by putting it in the water used for transplanting (from 200 to 800 gallons per acre), gave near perfect control of the sub-surface feeding coleopterous larvae. Granular forms of insecticide were ineffective but a pre-planting dipping technique is still under investigation.

Dusts in the planting hole were less effective as was banding the insecticide in the ridge in a double fertilizer band 8 inches on either side of the plant. Broadcasting the insecticide and mixing it with the soil during subsequent pre-planting cultural operations required four times the amount of insecticide to produce the same effect. Aldrin, dieldrin, chlordane and heptachlor have been compared and dieldrin has been recommended on the basis of greatest efficiency and persistence, and least phytotoxicity.

Some work has been started on the movement and persistence of these insecticides in soil following various methods of application.

Aphids and the Spread of Virus Diseases

The occurrence and behaviour of *Myzus persicae* (Sulz.) on tobacco has been studied for four years, with particular reference to the spread of two insect-transmitted viruses, rosette and an apparently new, and as yet undescribed, distorting virus. Sufficient data has been collected to advise farmers how to avoid the diseases by planting before a certain time of the year; or, if they wish to grow tobacco when Aphids are numerous, the most effective times to spray various plantings. In the course of this work, measurements have been made on the growth rate of the plants and the chemical composition of the leaves in order to study the relationship between these features and the behaviour of the Aphids. This work is continuing and in particular it is intended to make a special study of the water relationships of the plant and soil, the chemical composition of the leaves and aphid behaviour.

Rosette has been introduced into field tobacco using Aphids caged on the plants for various periods of time, in different positions on the plant, and on plants at various stages of growth. A fairly precise measure has been obtained of the effects of infection, both on the rate and pattern of growth and on the yield.

Laboratory investigations have been made on the acquisition and transmission of both viruses.

Four systemic insecticides (Systox, Metasystox, Thimet and Rogor(dimethoate)) have been tested with the aim of preventing or reducing spread, from crop to crop and within crops. Soil and spray applications have been compared. Rogor has been selected because of its low mammalian toxicity though some of the others were equally or more effective; residue and taint tests have been done with this compound and it is hoped to recommend its use to farmers in the 1960 season.

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* *Agrotis segetum, A. longidentifera, A. spinifera.*

† Species of Tenebrionid and Lamellicorn larvae.

Future work with insecticides will be concerned with studying the effects of systemics on the feeding behaviour of Aphids and the extent to which acquisition and transmission of viruses is affected.

FIJI

ECONOMIC ENTOMOLOGY IN FIJI

By B. A. O'Connor

Senior Entomologist, Department of Agriculture

During most of the period under review, shortage of staff has continued. Except for the period April 1956 to December 1958, when an entomologist was serving, the Senior Entomologist has been the only member of the professional staff.

The Rhinoceros Beetle—*Oryctes rhinoceros* (L.)

This pest, which was first discovered in Fiji in March of 1953, has now spread throughout the island of Viti Levu. Fortunately this island is not a significant producer of copra and the object of the control campaign is to prevent the establishment of the beetle in the more important copra-producing islands. Control activities include quarantine measures, inspection of properties with a view to enforcement of regulations governing the destruction of breeding places, and treatment of the crowns of palms in the more important areas with a mixture of BHC 50 per cent. dispersible powder and sawdust. Wettable powder formulations of diazinon and Sevin have been shown to be more effective than BHC, but at present their cost rules them out. The first seven years of the control campaign have cost nearly £400,000. While expenditure at this rate would be quite uneconomic for normal control purposes, it is regarded as justified in an effort to prevent or delay the introduction of the Rhinoceros Beetle to the copra-producing islands. Meanwhile, the South Pacific Commission is conducting research into the possibility of effective biological control, as well as some work on chemical attractants.

Rice Yellows

This condition, caused by the feeding of large numbers of the delphacid leafhopper, *Sogata furcifera kolophon* (Kirk.), on rice plants, was recorded in most years from 1938 to 1953. During the years 1954 to 1958 inclusive there was no outbreak of the disease throughout Fiji, and it was thought that control had been accomplished by Mirid bugs of the genus *Cyrtorhinus*, which suck the eggs of the leafhopper. In 1959, however, we experienced the worst outbreak ever recorded, with an estimated loss of 30 per cent. of the crop. As compared with previous outbreaks, the 1959 epidemic exhibited the following features:—

(a) Whole fields of rice were killed as against the normal experience of the death of only some stems in stools occurring in scattered patches, and the plants were killed much more quickly.

(b) The plants collapsed without previously showing the normal symptoms of curling and an orange colouration beginning at the tips of the leaves.

(c) Dry rice as well as wet rice suffered severely.

(d) The attack persisted until the end of May, instead of clearing up about the end of March.

In the 1959–60 rice-growing season there has been no severe and widespread outbreak, probably due to well-distributed rainfall (Rice Yellows usually occurs after a week or two of dry weather). However, there have been numerous scattered infestations of some severity, and the pattern has again remained atypical. For instance, infestations occurred as early as November, and considerable damage was caused to both dry rice and seedbeds. Overall damage, however, has been very slight, owing to prompt treatment of affected crops with insecticides.

The Coconut Stick Insect—*Graeffea crouani* (Le Guill.)

An outbreak of this pest occurred during 1959 on a plantation on the island of Taveuni, the area involved being about 200 acres. The insect is present on coconut palms throughout Fiji, but normally is of little economic importance. Two species of egg-parasites are factors in its control. However, on occasion, outbreaks occur in scattered localities, involving areas of up to two or three hundred acres. Control by the use of insecticides has presented great difficulty, because of the lack of an applicator which could satisfactorily treat very tall palms under windy conditions. During 1959, however, a local air transport company had available a light aircraft fitted with a spraying apparatus, and the Agricultural Department hired this machine to conduct a spraying trial on the affected plantation on Taveuni. An area of 100 acres was treated, using a solution of BHC containing 20 per cent. γ isomer mixed with diesoline. Planned rates of application on two plots of 50 acres each were 4 oz. and 8 oz. of γ isomer per acre in 2 gal. of spray fluid. Actual rates were 4·4 oz. in 2·2 gal. and 10 oz. in 2·5 gallons. Both rates gave a kill of stick insects approaching 100 per cent.

BIOLOGICAL CONTROL OF INSECT PESTS AND WEEDS

The Rice Armyworm—*Pseudaletia separata* Wlk.

In October and November of 1956 the Tachinid, *Achaetoneura archippivora* (Will.), was introduced from Hawaii, about 500 adult flies being received. This fly has a very wide host range, but was imported primarily because it might assist in the control of the rice armyworm, of which there had been a severe outbreak earlier in the year. No difficulties were encountered in breeding the parasite, the hosts used being *Prodenia litura* (F.), *Spodoptera mauritia* (Boisd.) and *Heliothis armigera* (Hb.). In all, nearly 10,000 adult flies were liberated over a period of eight months, but no recoveries have ever been made in the field.

Fruitflies

The two local species of fruitflies are *Dacus passiflorae* Frogg. and *Dacus xanthodes* Broun. Two species of parasites, *Opius oophilus* Full. and *Opius longicaudatus* (Ashm.), which were originally introduced from Hawaii, have become established on the island of Viti Levu, *O. oophilus* being much the more important. As the damage caused by fruitflies has been much reduced during the last few years, it seems likely that *O. oophilus* has played a significant part in controlling the pests.

Banana Scab Moth—*Nacoleia octasema* (Meyr.)

This insect causes an estimated loss of at least 25 per cent. in exportable bananas, despite the common, though generally inefficient, use of insecticides to control it. Towards the end of 1956, R. W. Paine was appointed to conduct a search for parasites on the mainland of New Guinea. *N. octasema* had been recorded from New Guinea, but was not known to cause damage to bananas. Paine found scab moth on *Heliconia*, *Pandanus* and *Nipa* on the mainland of New Guinea, but not on *Musa*. It was attacked by a wide range of parasites, of which the Encyrtid, *Pentalitomastix nacoleiae* (Eady), was judged to be the most important. Consignments of this insect were sent to Fiji, where it bred successfully on the local scab moth. Great numbers of the wasps were liberated in the field, but only a few parasitised host larvae were recovered, and these were from plants in the immediate vicinity of liberation sites. The parasite apparently failed to become established, and it seems a reasonable deduction that it will not frequent banana plants.

It was decided to continue the search for effective parasites, this being made possible by a grant from the Colonial Development and Welfare Fund. In April 1959, Paine began a survey which included Malaya, the islands of Indonesia, Borneo and Timor. In Malaya, Borneo and Sumatra, scab moth was not found on bananas. It was found on bananas in Java, the Banda group, Flores and Timor. In Java, parasites were bred from material collected on *Nipa* palm, but not from collections on banana. Finally, the parasite *Chelonus striatagena* Cameron was bred from larvae collected on banana plants in Timor and Flores. Colonies were sent to Fiji in January and February 1960, and *Chelonus* is being bred and distributed in the field. It has been recovered from larvae collected near liberation sites, but its potential value as a control for scab moth is unknown.

The Small Coconut Leaf Moth—*Agonoxena argaula* Meyr.

A secondary objective in Paine's project has been a search for parasites which might be used to control *A. argaula.* The latter is a pest which seldom occurs in epidemic form, but is present on coconut palms throughout the Fiji Islands. One can only guess at the extent to which it affects copra production, but, apart from its effect on mature palms, it must appreciably lengthen the period which elapses before young palms come into bearing. Damage to the leaves of young palms is often quite severe. There is a complex of native parasites, but these exert only partial control.

In 1952 O'Connor had found two parasites of *Agonoxena pyrogramma* Meyr. in New Britain, namely a species of *Apanteles* and an unnamed Tachinid. Paine found several other species on the mainland of New Guinea, and forwarded a considerable amount of material to Fiji, where attempts at breeding met with little success. The only liberations of any significance were those of a species of *Elachertus.* It is not known whether this has become established. The Tachinid would be a welcome addition to the range of parasites in Fiji, as we have none belonging to the order Diptera. However, in captivity the adults all died within 24 hours. Paine will make another attempt to send this species to Fiji; in the meantime, he has sent a species of *Macrocentrus* which attacks *Haemolytis miniana* Meyr., an Agonoxenid which breeds on coconut palms in Java. Field liberations of this species have been made.

Lantana

As part of a joint project with Hawaii and Australia, Fiji receives shipments from Hawaii of insects which feed on *Lantana camara.* During the period 1954 to 1959 the following species have been received, *Blepharomastix acutangularis* (Sn.), *Diastema tigris* Gn., *Aerenicopsis championi* Bates, *Octotoma scabripennis* Guerin and *Syngamia haemorrhoidalis* Green. Of these, only *S. haemorrhoidalis* has become established. About 1,200 adults of this species were liberated over a period of eighteen months in 1958 and 1959 on the island of Viti Levu, where the moth is now established. Towards the end of 1959, colonies totalling 665 adults were liberated on the island of Vanua Levu. Shortly we are to receive consignments of the moth *Hypena jussalis* Walker, which has been very successful in Hawaii.

Tobacco Weed—*Elephantopus mollis*

During March and April of 1957 shipments of the seedfly, *Tetraeuaresta obscuriventris* Lw., were received from Trinidad. About 7,000 adult flies were liberated in the field, and the species quickly became established. It now occurs in vast numbers throughout the island of Viti Levu. Whether it will be able to control its host plant is a matter for conjecture, as the plant is a prolific seed-bearer.

GHANA

1. REVIEW OF ENTOMOLOGICAL WORK OF THE MINISTRY OF AGRICULTURE

By J. Forsyth

Although the Ministry has suffered from a severe staff shortage it is anticipated that the position will improve. Meanwhile benefit has accrued from the formation of a unit within the Cocoa Marketing Board to deal with storage pests of cocoa, particularly, but not exclusively. Cocoa has also continued to receive attention at the West African Cocoa Research Institute where, in co-operation with commercial interests and field assistance from the Cocoa Division of the Ministry, great progress has been made in control of mirids, with high benefit to the economy of the country. Cocoa is reported separately.

STAFFING

Professional staff in 1954 consisted of one Senior Entomologist, Mr. J. Bowden, and one Entomologist, Mr. J. Forsyth. In 1957 Mr. Bowden left on transfer to the Department of Agriculture, Uganda; in 1959, Mr. Forsyth retired to take up an appointment as Lecturer in Agricultural Entomology, University College of Ghana, and Mr. G. K. A. Buahin was transferred from general duties as Agricultural Officer (Entomology).

CROP PESTS

Pests of Maize

Bowden (1956b) described initial experimental work which has led to some field control of maize stem-borers, using 5 per cent. DDT dust applied with a pepper-pot shaker at 14 days, and repeated at 28 days, after planting. It soon became evident, however, that the use of DDT dust by farmers is limited by the cost of the insecticide relative to the low cash return for increased crop at the general level of yields.

In field trials carried out at a number of sites in Ashanti, southern Ghana and the Volta Region on plots from 5 to 23 acres and with plant populations varying from 3,400 to 10,600 increases in yield varied from 20 to 45 per cent. or from 138 to 266 lb. dry weight per acre, control yields varying from 326 to 1,183 lb. per acre. The crop is harvested in January when the price is usually around 30/– per bag of 224 lb. Thus, increased gross returns from dusting would range between 18/– and 35/– per acre.

A dusting trial using a tin can with holes punched by a 1-inch nail over the area covered by a West African penny, and a beer bottle fitted with a plastic press-on cap drilled with five $\frac{1}{16}$-inch holes, gave the following approximate costs per acre for the second dusting of a plant population of 10,000 per acre:—

Tins—insecticide (27 lb.) 17/6, labour 6/3, total 23/9
Bottles—insecticide (19 lb.) 12/2, labour 21/3, total 33/5

Assuming that the first dusting at 14 days requires about 0·75 of the above quantities, the total insecticide costs would have been 31/– for tins, 21/4 for bottles. If the farmer does not cost his own labour then the bottle method is cheaper although three times slower.

At the present price of insecticide, the economics of dusting is very dependent on careful usage.

Pests of Ground-nut

In Wenchi, Brong-Ahafo, a millipede *Peridontopyge* sp. has been recorded eating out 4 per cent. of ripening nuts before harvest.

Pests of Coconut Palm

A serious problem, arising from the death of about ten thousand coconut palms a year due to the 'Cape St. Paul Wilt' disease at Keta, has been the tremendous increase of Rhinoceros beetles, *Oryctes owariensis* P. de B. and *O. monoceros* (Ol.), which breed in the dead trunks and feed on the healthy palms.

At Keta, in 1953, it was found that on the average each dead palm harboured twenty-three larvae, two pupae, and two adult beetles. The adults chew through the petioles and intervening inflorescences of the healthy palms to feed on the young folded heart leaves. Young seedlings are often very severely affected and may be killed outright if the bud is damaged and secondary rots gain entry. From observations of larvae and pupae, collected from newly felled palms every week during twelve consecutive months of 1954–55, breeding appears to be continuous. The life cycle is eggs 3–6 days, larvae 7–9 months, pupae 20–24 days.

A spraying trial on immature palms (4–6 years old) showed that 0·3 per cent. dieldrin (emulsion concentrate) applied at 28-day intervals and 0·5 per cent. DDT (miscible liquid) applied at 14-day intervals give partial control against the adult beetles. The heart leaves were 'jetted' with 60 cc. spray using a Mysto sprayer fitted with a curved lance and bored out jet.

In all stages the beetles in the dead trunks are singularly free from predators or parasites and it was only during very wet weather that rotten pupae and larvae were collected. When the palms were felled, however, approximately eighty per cent. of the larvae were ejected onto the ground and perished. The remaining few left in the fallen trunk continued their life cycle in competition with termites, wood-destroying fungi, and owners who used the trunks for firewood. In 1954, the current phytosanitary campaign was launched in the heavily infested Cape St. Paul area where some of the farmers were attempting to re-establish their devastated farms. The campaign was later extended to cover all the diseased zones and by 1958 over 100,000 dead or diseased palms had been felled, and it was not long before the owners split these for firewood. The decrease in numbers of these pests must have been very substantial.

Pest of Oil Palm

A serious outbreak of the hispid leaf miner *Coelaenomenodera elaeidis* Mlk, occurred in July, 1959 on plantations in Western Region. By December, infestation was so heavy that only the 'spikes' of the trees were green; the rest of the plantation was a dirty brown colour.

Pests of Coffee

The coffee berry borer, *Stephanoderes hampei* (Ferr.), is considered to be the most serious pest in Ghana. Sampling of farmers' crops carried out in 1957 in Ashanti after harvest showed that from 8 to 60 per cent. of the berries were infested. The standard of agronomy on most coffee farms is very low.

In 1956 larvae of a moth, *Lecethocera* sp., caused serious damage to growing tips at Juaso, Ashanti. A moth larva causing 'scorch' by rasping the lower leaf epidemis has been identified as *Leucoplema dohertyi* (Warren). Indications in a preliminary trial were hat endrin gave better control than dieldrin when applied as sprays.

STORED PRODUCTS

Crib Storage of Maize

In 1956 a trial was conducted on five methods of storing maize on the cob. The trial was carried out in a typical farmer's type crib and the treatments were:—

1. Ear plus sheath, random
2. Ear plus sheath, selected for soundness   no treatment
3. Ear minus sheath selected for soundness
4. As for (3) plus 5 parts per million γ BHC
5. As for (3) plus 12·5 parts per million γ BHC

The γ BHC was 0·45 per cent. dust applied with a 'pepper-pot' tin-can sprinkler. The trial lasted for a period of 6 months. Assessment of damage was used as a measure of the effectiveness of the treatments.

With the rice weevil, *Sitophilus* (*Calandra*) *oryzae* (L.), and the moth, *Sitotroga cerealella* (Ol.), the life history normally takes place in one grain; the emergence hole of the rice moth is always circular, and is smaller than that of the rice weevil, which is usually uneven in outline, only occasionally circular. Damage caused by the corn ear worm, *Mussidia nigrivenella* Rag., is characterised by damage to the germ of the grain.

Results showed that for *S. oryzae* Nos. 1, 2, 4 and 5 all had less damage than 3 ($P=0\cdot001$); for *S. cerealella* 2 and 5 had less damage than 3 ($P=0\cdot001$); for *Mussidia nigrivenella* 5 had less damage than 1 and 2 ($P=0\cdot001$) and 3 had less damage than 1 and 2 ($P=0\cdot05$); for total insect damage 5 had less damage than 3 ($P=0\cdot001$) and less damage than 1, 2, 4 ($P=0\cdot01$).

Treatment at 12·5 p.p.m. γ BHC thus gave significantly better results than all the other treatments.

Analysis of the residual γ BHC on the grain 9 months after storage showed that the nominal 12·5 p.p.m. had dropped to between 0·6 to 1·6 p.p.m. (the 12·5 p.p.m. was applied in relation to total ear weight, equivalent to about 21 p.p.m. on grain weight).

The commercially available dust for extension work is now 0·5 per cent. γ BHC. A convenient rate of application is 4 oz. per hundredweight which is equal to 11·1 p.p.m. on ear weight or 17·0 p.p.m. on grain weight. This rate of application is recommended to farmers and the response is very good in spite of the difficulty of demonstrating the economic advantage of treating the grain, since it is subsequently sold by volume.

In August 1958, the first season when extension sales were organised, 30,000 four-ounce packets of a proprietary 0·5 per cent. γ BHC dust were sold as well as 7 cwt. in bulk.

A further test on ears without sheath which had been dusted with 0·5 per cent. γ BHC dust at 4 oz. per hundredweight gave the following results for residual BHC in p.p.m.

Stored		
5 weeks	Shelled	0
	Shelled and winnowed	0·1
	Shelled, winnowed, washed	0
6 weeks	Shelled	5·8
7 weeks	Shelled	0·4
7 weeks	Untreated, shelled	NIL

The dusting was carried out by farmers in their own storage cribs. The analysis reference is Tropical Products Institute Report Ref. P.237/11 'Maize cobs from Ghana.' 1958.

Silo Storage of Maize

Maize storage co-operative units are now being run successfully in three villages in the maize growing belt of N. Ashanti. These co-operatives use oil-fired in-sack driers and 20-ton circular plywood silos. After drying, the maize is dusted with 0·5 per cent. γ BHC at the rate of 2 oz. per hundredweight as it is poured into the silo. This has been found to be effective against *S. oryzae* but not against *Tribolium castaneum* (Hbst.) which is present in small numbers. There have been some complaints of taint from the makers of kenkey (fermented dough) so the farmers now sieve the maize as it is withdrawn from the silos. There have been two reports of treated maize used in poultry rations causing taint to eggs and bird flesh.

Storage of Sorghum and Millet in N. Ghana

The species of insects found were, in rough order of frequency of occurrence:—*Tribolium confusum* Duv., *Lasioderma serricorne* (F.), *S. oryzae* (now known to include *Calandra sasakii* Tak.), *Sitotroga cerealella*, *Rhizopertha dominica* (F.), *Palorus* sp., *Cryptolestes* sp. *Oryzaephilus* sp. *Corcyra cephalonica* (Stnt.).

The present practice of sun-drying of Guinea corn and late millet together with a high standard of granary hygiene by the farmer normally ensures a low level of insect attack during the first six months of storage. Application of 11 parts per million γ BHC dust to heads of guinea corn and late millet makes no practical difference to the level of insect damage during the first six months of storage, but may be economic over a storage period longer than six months. It may also be economic when applied to early millet which is not dried before storage.

TAXONOMY AND INSECT IDENTIFICATION

Bowden (1956a) has published further results of his work on the taxonomy of African stem-boring Agrotidae (Lepidoptera).

It is a pleasure to record the help and assistance received from the Commonwealth Institute of Entomology in the identification of material collected in the field over a wide range of groups.

An index has been compiled of pest species so far recorded off crop plants in Ghana, and it is intended that this material will be published as a check-list in the not too distant future.

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2. REVIEW OF WORK ON THE CONTROL OF INSECTS IN STORED FOOD PRODUCE

By JOHN RAWNSLEY

Ghana Cocoa Marketing Board

In Ghana the problem of insect pests of stored produce is centred mainly on cocoa. About one-quarter of a million tons of cocoa are produced each year and in the last two years the maximum storage period in this country has been about five months. All aspects of the control of insect pests in stored cocoa are carried out by the Board.

By agreement with the Ministry of Food and Agriculture, Ministry of Trade and Industries and Ministry of Health and Social Welfare the Insect Control Unit of the Cocoa Marketing Board also deals with the control of pests in stored cereals and cereal products, oil seeds and oil seed products and any other stored food. This relatively small amount of work is dealt with easily within the routine programme for the control of pests of stored cocoa. The control of stored products in this country, which was previously thought to require Government legislation, is therefore now being dealt with entirely by normal administration.

COCOA

Cocoa is produced by many thousands of small farmers and after local fermentation and drying it is bagged, collected into large stacks at the main up-country centres and eventually sent to the ports for shipment. The principal storage pests are the moth *Ephestia cautella* (Wlk.) and the beetles *Lasioderma serricorne* (F.), *Araecerus fasciculatus* (DeG.), *Tribolium castaneum* (Hbst.), *Ahasverus advena* (Waltl.).

All these species are very widespread throughout the cocoa growing areas on all kinds of agricultural produce grown and consumed by the farming population. The origin of insect pests in cocoa occurring in storage has been found to be mainly by cross-infestation from local food supplies such as legumes, dried cassava and plantain, and various cereal grains. The eggs are laid soon after the cocoa is dried in the many scattered villages, the first generation of the adults emerging about 2–3 months after drying, that is after the cocoa has been bagged and stacked at the main up-country centres.

To a great extent the control of insects in stored cocoa in this country is determined by the wishes of chocolate manufacturers. Manufacturers require that there should be no insecticide or any other extraneous matter admixed with the beans. This is because the quality of cocoa depends to a large extent on its being untainted. Apart from this, it would be impracticable to control insects by the admixture of insecticides with naked beans because the application of such insecticide would have to be made in the many scattered up-country villages before the cocoa is bagged. At the present time, it would be impossible to keep the necessary strict control on the application of insecticides in that way. We are, therefore, limited to those methods which can be properly controlled and supervised at the main centres and ports and which do not cause any contamination of the beans.

The habits, life cycle and biology of the insect pests is considered here to be the key to their control. In this respect the cocoa moth *E. cautella* becomes naturally separated from the beetles and for convenience, it is treated separately.

The Cocoa Moth—*Ephestia cautella* (Wlk.)

The first eggs are laid shortly after the cocoa is dried and the larvae develop mostly within the beans, and to some extent between them. The mature larvae migrate to the outer part of the stack and pupate mainly on the external surfaces. *E. cautella* differs from the temperate climate species, *E. elutella* (Hb.), in that the larvae of *E. elutella* migrate from the stacks of produce and pupate on the structures of the warehouse. Another fundamental difference between the two species is that the tropical *E. cautella* has a continuing cycle whilst the cycle of *E. elutella* is seasonal and includes an over-wintering diapause.

The first emergences of the adults of *E. cautella* usually begin about 2 months after the beans have been dried—this is when the cocoa is in large stacks in the main centres. Because the cocoa in one stack (often more than 100 tons) is of divers origin and many different ages, the emergence of adults becomes continual. Emergence from the pupal cases occurs mainly in the late afternoon and is followed by a dusk flight, after which the adults settle and mate. The females are capable of laying viable eggs by the following morning. One of the extremely important facts discovered here is that females knocked down and killed by insecticides lay eggs which are viable almost to the same extent as eggs laid by normal females. The first larval stage of *E. cautella* is capable of wandering for many yards without food, so that an infestation may progress even from viable eggs laid on structures by knocked-down females.

It is, therefore, necessary to achieve a high percentage kill of adults every evening so as to prevent the maturity of mated females. A system has been developed of insecticidal fogging which is carried out in every shed in every main centre and port every evening at about dusk. The fog is injected into the shed from outside by means of portable thermal fogging machines. The fog has a base of odourless paraffin and an insecticidal ingredient of pyrethrins. The concentration has been adjusted so as to achieve an almost 100 per cent. kill. There is good evidence that the system has been an effective control measure. The fog is a space treatment with a non-toxic and odourless substance and does not make direct contact with the beans.

This system of insecticidal fogging is supplemented with the application of insecticidal whiting to the inside surfaces of cocoa sheds. Insecticidal whiting is still in the experimental stage here but it is probable that it will be adopted generally in the near future. Research is being carried out with several insecticides which have a long residual high toxicity and a tolerance to a high alkalinity. This tolerance to a high alkalinity is necessary because it is only practicable to use the whiting made from the hydroxide of lime. This system also has the advantage in achieving a kill of insects which settle on the walls, no insecticide being applied to the beans themselves.

Beetle Pests

The beetles infesting stored cocoa have a very different habit from the cocoa moth. The infestation begins very soon after the cocoa is dried but the life cycles continue within the beans inside the bag. Adult beetles emerge from the stacks of cocoa only to a very small extent. Fortunately the natural rate of development of beetle infestation is slower than that of the cocoa moth. The larvae of *Araecerus fasciculatus* and *Lasioderma serricorne* are immobile and develop entirely within the beans. The life cycle of *L. serricorne* in cocoa is about two months, that of *A. fasciculatus* about three months. The other beetles have life cycles of 2–3 months and the larvae develop to some extent inside damaged beans but mainly between the beans.

Beetle infestations are controlled, where necessary, by fumigation with methyl bromide. This is a highly penetrative and easily dispersed gas with high toxic properties. It is fortuitous that the toxicity of methyl bromide against insects increases greatly with increased temperature. We have found that under our tropical conditions, it is possible to achieve an almost

100 per cent. kill of insects (including immobile larvae within beans) by using only 32 oz. of the gas per 1,000 cubic feet for 4 hours, either in stacks covered with gas-proof sheets or in lighters at the ports before shipment. In lighter fumigations in fine weather the gas-proof sheets are removed entirely and because of an almost continual south-west breeze the ventilation period is very short. In bad weather the gas may be forcibly extracted before removing the gas-proof sheets. In the fumigation of stacks under gas-proof sheets inside cocoa sheds the gas is forcibly extracted by powerful contra-rotating aerofoil fans mounted on mobile units. Nineteen-inch diameter ducts are led from the stack to the extraction fan. This system has the advantages of safety to personnel, rapid and complete extraction of the gas and causes no disruption of normal working in cocoa sheds up-country or at the ports. The sheets are removed after all the gas has been dispersed and it is possible to clear 200 tons completely of gas in less than half an hour. The system is entirely mobile.

During the last season we have been able to meet all our demands for insect-free cocoa.

Cocoa stacks once fumigated are still liable to reinfestation from external sources. This is particularly true in the case of *E. cautella*, the adults of which are very mobile. Subsequent routine control measures are, therefore, still necessary.

An extremely important aspect of insect control in cocoa storages is rigid hygiene. This will be assisted in the small collecting centres by the use of insecticidal lime wash. In the main centres a system of high-powered vacuum cleaning is being developed. The cleaners are of the 3 horse-power type, electrically driven either from mobile generators or from mains supply.

OTHER COMMODITIES

Maize

Large bulks of maize imported from the United States of America became very heavily infested both with insects introduced with the maize and with indigenous species. Methyl bromide fumigation was carried out and a hundred per cent. control was achieved. The interesting feature of this case is that the moth *Plodia interpunctella* (Hb.), which was unknown as a pest in this country, was introduced with the maize and developed very rapidly. It is possible that the spread of this moth was cut short, but we cannot be certain yet. It could be a serious pest of home-grown grain.

Rice

A great deal of rice imported from the East is heavily infested with many species including the moth *Corcyra cephalonica* (Stnt.) which is at the present time very uncommon in this country. Fumigation has been used as a control measure.

Flour

It is unusual for flour to be stored for more than one month in this country (all wheat flour is imported) but in several cases where flour was stored for four months it became heavily infested. It was effectively fumigated with methyl bromide.

Imported Beans

Small white beans imported from Nigeria have been found to carry *L. serricorne*, one of the serious pests of cocoa. In the survey of these beans, the first recording in this country was made of the beetle *Trogoderma granarium* Everts, also on beans imported from Nigeria. These beans are also fairly widely produced in Ghana and sustain heavy losses due to bruchid beetles. In a good many cases losses of 6–10 per cent. have been recorded. This has been determined by comparing the weights of large numbers of beans cavitated by bruchid larvae with the weights of large numbers of uninfested beans. Control of the infestation of home-produced beans remains a problem because of the scattered marketing practice. It is hoped that in the future there may be a Government controlled co-operative market which would necessitate the bulk collection of beans shortly after harvesting. It would then be possible to prevent these serious losses by means of methyl bromide fumigation or by other insect control measures.

Oil Seeds and Oil Seed Products

The insect pests of these products during storage are controlled by routine insecticidal fogging and fumigation.

GREAT BRITAIN

RESEARCH ON ECONOMIC ENTOMOLOGY

Responsibilities in the field of economic entomology in Great Britain may be indicated broadly as follows:—

ENGLAND AND WALES

Research on agricultural, horticultural and stored product pests.	Agricultural research institutes and certain Agricultural Research Council (A.R.C.) Units.
Technical advice to the Ministry of Agriculture, Fisheries and Food (M.A.F.F.) on pest intelligence, crop certification schemes and on insecticides, fungicides and herbicides, etc.	Plant Pathology Laboratory, Harpenden.
Control of stored product pests.	M.A.F.F. Infestation Control Division, Tolworth.
Advisory and field experimental work in agriculture and horticulture.	National Agricultural Advisory Service (N.A.A.S.).
Forest insects.	Forestry Commission Research Station, Farnham, Surrey.
Timber insects.	Department of Scientific and Industrial Research (D.S.I.R.) Forest Product Research Laboratory, Princes Risborough, Bucks.
National collections and identification.	British Museum (Natural History), South Kensington.
Abstracting of literature and Commonwealth information and identification service.	Commonwealth Institute of Entomology.
Miscellaneous research projects.	University Departments of Zoology and Agriculture.

SCOTLAND

Technical advice to the Department of Agriculture and Fisheries for Scotland (D.A.F.S.).	D.A.F.S. Scientific Services, Corstorphine, Edinburgh.
Advisory and experimental work.	Advisory entomologists in North, East and West of Scotland Agricultural Colleges.

The greater part of the research in economic entomology is carried out in the entomology and insecticides departments of the agricultural research institutes, which are under the general oversight of the Agricultural Research Council. A certain amount is also done in two A.R.C. Units attached to Cambridge University—the Unit of Insect Physiology and the Virus Research Unit. Research on insect pests of hops is the responsibility of the Department of Hop Research, Wye College, University of London, and is financed partly by the A.R.C. and partly by the industry concerned. The A.R.C. also supports some research in University Departments by means of short-term research grants.

Much entomological research, very varied in character, is done by the Universities themselves, most of it in the Departments of Zoology or Agriculture. Much of this is of a fundamental nature, covering physiology, taxonomy, life-history studies, etc., but some of it is definitely on pests of economic importance. A list of research projects in Universities is published periodically by the Department of Scientific and Industrial Research.

The Ministry of Agriculture, Fisheries and Food has two laboratories with departments of entomology—the Plant Pathology Laboratory at Harpenden and the Infestation Control Division at Tolworth. The former works in close liaison with the entomologists of the

National Agricultural Advisory Service and the latter acts as the scientific headquarters of the Regional Pests Officers.

The Plant Pathology Laboratory, in collaboration with a special Pest Assessment Committee of the N.A.A.S. entomologists, has established a scheme for assessing the economic losses caused by the main agricultural pests. Estimates have already been made of the losses caused by such pests as the cabbage aphid and frit fly of oats and further work is in progress on other important pests. An account of this work is included in the Report of the Agricultural Research Council for the year 1958–59.

Among its many other duties, the Plant Pathology Laboratory provides the technical services for an official Approval Scheme for the efficient use of agricultural chemicals employed in crop protection and acts as a clearing house for information on the toxicity of pesticides to man, animals and plants.

The work of the National Agricultural Advisory Service is divided between eight regions, with headquarters in the Ministry of Agriculture, Fisheries and Food in London. There are eight regional centres and four sub-centres, at each of which there are a number of entomologists on the staff. The duties of these comprise, besides general advisory work, the assessment of pest incidence and a certain amount of field experimental work. Many papers by advisory entomologists, describing experimental work on specific pests, are published in the journal *Plant Pathology*, edited by the Plant Pathology Laboratory at Harpenden.

Mention must also be made of the very considerable amount of research and experimental work done by entomologists in industrial firms specialising in the production of insecticides. A number of the bigger firms have well-equipped laboratories where new chemicals are screened and where tests are made on formulation methods and all other factors affecting insecticide performance.

During the period under review there has also been an expansion in nematological research. Rothamsted has been active in this field for a number of years; for some time there has been a nematologist on the staff of East Malling Research Station and recently one has been appointed to the Glasshouse Crops Research Institute. There is also a nematologist on the staff of the M.A.F.F. Plant Pathology Laboratory at Harpenden. In 1955 a Chair of Parasitology was established at the Imperial College of Science and Technology, the first holder of which is Professor B. G. Peters, formerly head of the Nematology Department at Rothamsted; it is therefore to be expected that an active centre of research in agricultural nematology will now develop there.

It is not possible in a review of this kind to give an exhaustive catalogue of all work on economic entomology done in Great Britain in the past five years. No more will be attempted here than to sketch the main lines of recent and current work at the various research institutes and Units under the aegis of the Agricultural Research Council. A list of the institutes and Units doing research in economic entomology is given below. Fuller details of the work of each can be obtained from the annual reports published by all except the two Units.

RESEARCH INSTITUTES AND A.R.C. UNITS DOING WORK IN ECONOMIC ENTOMOLOGY

Rothamsted Experimental Station, Harpenden, Herts.
    Departments:—Entomology; Bee Research; Nematology and Insecticides and Fungicides.

Glasshouse Crops Research Institute, Rustington, Littlehampton, Sussex.
    Departments:—Entomology and Crop Protection.

East Malling Research Station.
    Departments:—Entomology and Plant Protective Chemistry.

Agricultural and Horticultural Research Station, Long Ashton, Bristol.
    Departments:—Entomology and Chemistry.

National Vegetable Research Station, Wellesbourne, Warwick.
    Department:—Entomology.

Pest Infestation Laboratory, Slough.
    Departments:—Biology; Insecticides; Fumigants and Biochemistry.

Scottish Horticultural Research Institute, Invergowrie, Dundee.
Unit of Insect Physiology, Department of Zoology, University of Cambridge.
Virus Research Unit, Cambridge.
Department of Hop Research, Wye College, Ashford, Kent.

Rothamsted Experimental Station

Entomology

The work of the department extends beyond insects to other pests, such as slugs, and to the general soil fauna, special attention being given to earthworms. Ecological studies on the population, distribution and spread of insects will, it is hoped, help in the improvement of control methods by both biological and chemical means. Work on wheat bulb fly was intensified in 1953 after severe damage to crops in many parts of Britain. An investigation of the biology and ecology of frit fly is in progress in collaboration with the Pest Assessment Section of the M.A.F.F. Plant Pathology Laboratory, Professor O. W. Richards and his staff at Imperial College of Science, and Mr. A. Ibbotson of Durham University.

The effects of climatic factors on insect physiology have been studied with particular reference to acclimatization, dispersal and the way in which insect pests locate host crops.

Ecological studies of the soil fauna, including not only insects but also earthworms, slugs, millipedes and mites, have been carried out in fallow, grassland, orchard and forest. A collaborative study of the rehabilitation of farmland after open-cast coal mining is being undertaken with Durham University.

The importance of predation by spiders for the biological control of insect pests and the natural enemies of Aphids are also under investigation, the particular emphasis with Aphids being their role in the transmission of virus diseases.

Bee Research

The social organisation of bees has been studied with particular reference to swarming, drifting, queen-balling and the significance in behaviour of the state of development of the hypopharyngeal glands. In a joint study with Dr. S. A. Barker and his colleagues of Birmingham University and Dr. R. K. Callow and Miss N. C. Johnston of the National Institute for Medical Research, the presence of 10-hydroxy-$\triangle^2$-decenoic acid in the mandibular glands of worker bees has been established. Dr. Callow and Miss Johnston have also been co-operating in the determination of the chemical nature of " queen substance " which has been found to be 9–oxodec–2–enoic acid and has been synthesised by them. This substance inhibits workers from raising queens and when given to queenless workers prevents development of their ovaries. It is thought to be of importance in colony management because queens that have been superseded or have swarmed from uncrowded colonies contain less of the substance than those in normal colonies of the same size.

A number of bee diseases are being investigated. It has been established that European Foul Brood is caused by *Streptococcus pluton*, disease being aggravated by secondary infection with *Bacterium eurydice*. Other studies have been made on American Foul Brood, Nosema and Acarine diseases, the incidence of the latter being inversely related to the amount of nectar available. During 1955, a year of good nectar flow, infection fell abruptly; in 1956, a year of virtually no nectar flow, it rose again; and in 1957, an average year, infection remained steady.

Nematology

Studies have been made on the soil population and on movement of larvae of cyst-forming nematodes of the genus *Heterodera*: potato-root eelworm, *Heterodera rostochiensis*; cereal-root eelworm, *H. major*; pea-root eelworm, *H. göttingiana*; beet eelworm, *H. schachtii*, and cabbage-root eelworm, *H. cruciferae*. The existence of biotypes of potato-root eelworm capable of breaking the resistance of crosses between *Solanum tuberosum* ssp. *tuberosum* and *S. tuberosum* ssp. *andigena* has been confirmed. Examination of field populations showed that about half contained appreciable numbers of resistance-breaking females and pot tests indicated that their proportions in populations increased each time resistant potatoes were grown.

Work is continuing on the isolation and characterisation of the potato root eelworm hatching factor in collaboration with the Biochemistry Department. The factor has been obtained in a high state of purity and its molecular weight determined.

Studies on beet eelworm have been concerned with the influence of soil moisture on larval activity both as a direct effect and indirectly through the host plant.

Four common species of *Collembola* have been shown to be predatory on the cysts of *Heterodera cruciferae*.

Work has started on chrysanthemum eelworm, *Aphelenchoides ritzema-bosi*, and a technique devised for infecting plants with known numbers of worms.

Research on nematicides is being developed and experimental work has been undertaken with " Vapam " and methyl bromide; earlier field experiments showed that " DD-mixture " at 300 lb./acre would control certain migratory soil nematodes including species of *Pratylenchus*. Survey work on the incidence of other migratory nematodes of the genera *Tylenchorhynchus*, *Tylenchus*, *Rotylenchus* and *Paratylenchus* is in progress. A species of *Xiphinema* which had been shown independently to be a plant virus vector by the Plant Pathology Department, Rothamsted, the Scottish Horticultural Research Institute and East Malling Research Station was identified as *Xiphinema diversicaudatum*.

Much work has been done on the identification, description and taxonomy of new species of nematodes and many specimens have been received from abroad for identification.

Insecticides and Fungicides

The main objectives of the work of this department are to study the mode of action of insecticides, the factors that influence their toxicity and how best to use them in practice.

The effect of temperature changes on the speed of action and toxicity of several insecticides has been studied. Formulation has an important effect on the phytotoxicity, strength and persistence of insecticidal seed dressings, such as BHC and Thimet. The seed-dressings that gave useful control of wheat bulb fly were dieldrin, γ-BHC and heptachlor.

The aphid vectors of certain virus diseases, notably sugar beet yellows and potato leaf roll, have been controlled by early spraying with efficient aphicides. Systemic insecticides have been used successfully to control *Aphis fabae* Scop. on broad bean and the general effect of aphicides on beneficial insects is under investigation.

A number of insect esterases have been isolated and their properties determined as part of a study on the mode of action of organo-phosphorus insecticides. The object is to try to determine the biochemical systems important in the poisoning of insects by organo-phosphorus compounds and to develop new compounds more toxic to insects but with a lower mammalian toxicity. It has been demonstrated that diazinon (O,O-diethyl O–2–isopropyl–4–methyl–6–pyrimidynyl phosphorothioate) which knocks down house flies, has less effect on the cholinesterase activity of their brains than their thoracic ganglia. Resistance of certain strains to diazinon differs; one strain remained resistant from generation to generation without being continually exposed to the poison.

The relation between chemical structure and insecticidal activity in the pyrethrins and related compounds is being studied. This work has included examination of pyrethrum extract for its insecticidal constituents and the isolation of pyrethrins I and II and cinerins I and II. The effect of synergists on toxicity is also being studied.

The factors influencing the toxicity and persistence of residual films of insecticide on plant and other surfaces are being studied and techniques have been developed for the bioassay of insecticides applied in this way. Insecticides present in poisoned bees have been bioassayed using second instar larvae of *Aëdes aegypti* (L.) and adult *Drosophila melanogaster* Mg. as test organisms. Parathion, DDT and arsenic were the most commonly found toxic compounds.

Glasshouse Crops Research Institute

Entomology

Research on the glasshouse red spider mite has shown that there is a complex of two species, *Tetranychus urticae* Koch and *T. cinnabarinus* (Bdv.). The former has green summer females and diapauses in winter, the latter has reddish-brown summer females and does not hibernate during the winter months. Cross-breeding tests between populations of these mites from Europe and America have shown that *T. bimaculatus* Harvey, the American two-spotted mite, is synonymous with *T. urticae* Koch.

Studies of the agromyzid fauna of ornamental plants are in progress, with emphasis on the parasite complex associated with *Phytomyza atricornis* Mg. and the factors governing the choice of oviposition site in this polyphagous species.

The biology of the glasshouse white-fly, *Trialeurodes vaporariorum* (Westw.), has been re-investigated with particular reference to its parasitism by the chalcid wasp, *Encarsia formosa* Gahan, to the assessment of populations, and to the determination of the economic effects on the cropping of tomatoes. A limited experiment on the use of the parasite as a control measure showed reductions in white flies of the order of 90 per cent.

The biology of insect pests of mushroom (Cecidomyiids, Phorids and Sciarids) is being intensively studied. It appears that only four species of paedogenetic Cecidomyiids are serious pests in the United Kingdom, and of these *Heteropeza pygmaea* Winn is the most common. Experiments are in progress on the effect of temperature on the rate of larval development, the effect of the pest on cropping, and the control of the pest by insecticides. Studies on the commonly occurring Phorid, *Megaselia halterata* (Wood) have led to the discovery that it can be parasitised by an eelworm, *Bradynema*, which renders females infertile. The life history of the eelworm and the host-parasite association are being studied to see whether there is any promise of developing an economic method of biological control.

Crop Protection

The control of the glasshouse red spider mite on cucumber is difficult because the mites are commonly resistant to organo-phosphorus compounds, including systemic compounds, and the host plant is susceptible to damage from many of the persistent acaricides normally used on other crops. Investigations on the control of this pest are in progress, and particular attention is now being paid to the problem of resistance. Almost complete eradication of non-resistant red spider was achieved following one application of diazinon aerosol applied at 1·5 g. per 1,000 cu. ft., but there was little ovicidal action or persistence. There is a potential hazard to the consumer in the use of diazinon since a period of 14 days is recommended between the last application and harvesting the crop. However, residues determined on cucumbers suggested that there was no risk with aerosol applications under greenhouse conditions. Tedion (2,4,5,4′-tetrachlorodiphenylsulphone) was also tested and was shown to have pronounced ovicidal activity but it was not so effective against adult mites. In tests with systemic organo-phosphorus insecticides applied to the soil, Thimet was readily absorbed in acaricidal amounts; Rogor was either less readily absorbed, more rapidly converted to an inactive form in the plant, or was less toxic to the mites; Phosdrin was not translocated in sufficient amounts to give control. Investigations of the efficiency and persistence of acaricidal action of some systemic compounds applied to the soil to control red spider on carnations showed that Thimet was the most persistent, methyl-demeton, Rogor and morphothion less so, and Phosdrin much less persistent.

Aphids have been controlled on lettuce with fluoroacetamide. As this insecticide is highly toxic its use in solution cannot be recommended on this crop, but advantage was taken of the fact that it is volatile to develop an effective method of control with the vapour form although there was some damage to plants.

The persistence of DDT, BHC and diazinon in mushroom composts has been studied to determine the most effective means of controlling mushroom flies.

East Malling Research Station

Entomology

Apple seedlings resistant to woolly aphid have been raised from crosses of Court Pendu Plat × Northern Spy and Cox's Orange Pippin × Northern Spy; many of them have maintained their resistance over a number of years.

Studies of the naturally occurring races of *Amphorophora rubi* (Kalt.), the aphid vector of certain raspberry virus diseases, have assisted the incorporation of resistance to the vector in breeding new varieties.

A comparative study of the effects of two spray programmes on the fruit tree red spider mite, *Metatetranychus ulmi* (Koch), and its predators was continued throughout the period under review. In 1959, an abundance of the black-kneed Mirid *Blepharidopterus angulatus* (Fall.), resulted in mite populations being reduced to a very low level, comparable with the situation in 1956, and thus completing a second cycle in predator-prey interaction. In 1958, direct evidence was obtained elsewhere of the occurrence of mites resistant to the hitherto effective acaricide chlorbenside. The nature and development of such resistance is being studied, both in the field and among laboratory-reared populations of mites.

The relationships between *Bryobia* mites found on apple, pear, gooseberry, ivy and grasses are being investigated by life history studies and host preference tests. Detailed biological studies have been made of species of Aphids infesting apple, pear, currant, gooseberry and *Prunus* spp.

It has been established that the overwintering forms and summer generations of pear sucker on cultivated plants comprise only one species, *Psylla pyricola* (Foers.).

Apple sawfly, *Hoplocampa testudinea* (Klug), has been successfully controlled with concentrate sprays at about 3 gal./acre.

The life histories of the strawberry seed beetle, *Harpalus rufipes* (Deg.), blackcurrant gall mite, *Phytoptus ribis* (Westw.), and raspberry beetle, *Byturus tomentosus* (Deg.) have been studied with the object of developing more effective means of control.

Soil migratory nematodes are being investigated with particular reference to slow decline in apples, replant problems in apples and cherries, and poor root development and decline in strawberries. The most important species appears to be *Pratylenchus penetrans* (Cobb). Infestation of strawberry plants by the leaf and bud nematode, *Aphelenchoides ritzema-bosi* (Schwartz) has also been followed. The role of *Xiphinema diversicaudatum* (Micol.) as a plant virus vector was established in collaboration with the Plant Pathology Section.

Plant Protective Chemistry

The toxicity and persistence of insecticide deposits, particularly DDT, are regularly determined and the compatability of various pesticides, such as DDT, BHC, aldrin and dieldrin with lime sulphur, is being examined.

Studies have been made in collaboration with the Entomology Section on the integrated biological/chemical control of insect pests in the orchard with the object of developing effective minimal spray programmes. A close watch is kept on the killing of beneficial insects by pesticides such as occurs through the evolution of hydrogen sulphide by lime sulphur deposits. General problems concerned with the phytotoxic effects of pesticides are also being studied.

Also in collaboration with the entomologists the naturally occurring insecticide, ryania, was compared with lead arsenate and DDT for the control of codling moth and was shown to be intermediate in effect. Systemic organo-phosphorus insecticides and a carbamate were compared with the standard BHC/DDT treatment against pests present at, or soon after, bud-burst on apple. All were effective against Aphids but only one against apple sucker. In view of the tolerance to chlorbenside shown by the fruit tree red spider mite several alternative acaricides were tested. Adequate commercial control up to the end of August was given by one application (on 25th May) of phenkapton, dimethyl S–(N–methylcarbamoylmethyl) phosphorodithioate, Tedion or 2,2,2–trichloro–1,1–bis(p–chlorophenyl)-ethanol.

Harvest residues of insecticides have been determined on various fruits, including strawberries and blackcurrants. A bio-assay technique, using *Drosophila melanogaster* Mg., has been developed for the determination of sub-microgram amounts of dieldrin, endrin and dimethyl 1–methoxycarbonyl–2–methylvinyl phosphate.

Agricultural and Horticultural Research Station, Long Ashton, Bristol

Entomology

The biology of insect pests of fruit is being investigated by means of population studies, particularly on Aphids infesting apples including the oat apple aphid, *Rhopalosiphum insertum* (Wlk.); rosy leaf aphid, *Sappaphis plantaginea* (Pass.): woolly aphid, *Eriosoma* *lanigerum* (Hsm.); *Aphis fabae* Scop.; *A. pomi* Deg. and *Macrosiphum euphorbiae* (Thos.) and on leaf hoppers, of which the two main species are *Typhlocyba debilis* (Dgl.) and *T. froggatti* Baker. A number of pests of willows which cause deformation of the rods and damage to the stools (button top midge, willow weevil and willow bean-gall sawfly) have also been studied. The biology of the big bud mite of blackcurrants is under re-investigation as a basis for further work on control measures and on the transmission of the virus causing reversion.

The mode of action of insecticides is being investigated by means of their effects on the respiration and on the muscle and nerve tissues of the cockroach, *Periplaneta americana* (L.), the migratory locust, *Locusta migratoria migratorioides* (R. & F.), and the grain weevil, *Sitophilus granarius* (L.). With adult males of locust, the insecticidal activity of paraoxon was found significantly greater than that of all other nitrophenyl phosphorus compounds tested. This may be attributed to the direct action of the compound, involving no change from inactive to active form *in vivo*, and also to better translocation of the compound from the point of application to the site of action. The effect of DDT in increasing the respiration rate was demonstrated with muscle tissue and nerve ganglia of the cockroach. The effect on toxicity of substitutions on the molecule has been tested with DDT and some organophosphorus insecticides. *In vitro* tests of toxicity have also been carried out using extracted insect esterases. Such tests have shown that organophosphorus compounds possessing the phosphoryl group have a high inhibitory activity and those with the thiophosphoryl group a low activity.

A study has been made of the timing of the application of spring washes and the advantages to be gained by the inclusion of a wetter in the sprays. Experiments with the precision siting of DDT and BHC emulsions at the " green cluster " stage of apples showed that BHC was superior to DDT for the control of *Aphis*; addition of a succinate wetter improved the performance of DDT but had little effect on the BHC treatment. Emulsions with high-wetting properties gave complete control of Aphid at full " pink-bud " stage without apparent interference with fruit set.

The toxicity of DDT deposits on apple shoots to larvae of the winter moth, *Operophtera brumata* (L.), was investigated. First and second stage larvae were killed almost immediately by surface deposits of about 4μg/sq. cm., whereas third and fourth instars required a longer exposure before being killed.

An investigation of wetting agents has shown that ionic surface-active agents are far more phytotoxic than non-ionic agents. Techniques are being developed for the use of fluorescent materials as tracers in spray formulations; these will be of particular value in determining the distribution and coverage of spraying techniques being developed at Long Ashton. An electronic particle resolver is used for studies on spray spectra. The investigations on spraying techniques include tropical crops such as banana, coffee, tobacco, coconut, abaca, hemp, etc.

Chemistry

Micro-methods have been developed for the assay of insecticides as deposits on plant surfaces or present within plant tissues. Accurate determinations of the initial deposits and the amounts of pesticide retained are required to assess the efficiency of spraying methods; DDT deposits were determined on apple and pear fruits in a comparison of the efficiencies of hand, automatic hydraulic and mist-blower applications. A method for the measurement of small quantities of dieldrin, applicable with lower sensitivity to aldrin, has now been evolved.

Physico-chemical methods are being used to measure the efficiency of spray machinery, such as the factors influencing the disintegration of a fluid jet as it leaves the spraying orifice.

^{32}P–labelled demeton–S has been used to trace the movement of a systemic insecticide through a plant.

The formulation of the spray material and the nature of the surface treated have been found to influence the deposit obtained and the extent of the phytotoxic damage. This has stimulated a study of the nature of the cuticle of leaves of broad bean, dwarf bean, pea, cabbage, laurel, tomato and pear, and of fruits of gooseberry, tomato and apple. Determinations have been made of the true wax, oil, volatile and acidic components, and the composition of Cox and Worcester leaf waxes has been shown to fluctuate throughout the season.

National Vegetable Research Station

Extensive studies have been made on the biology and control of the cabbage root fly, *Erioischia brassicae* Bché, and on the damage to yield and quality caused by this pest. Satisfactory control in the seed bed was achieved by spraying seedlings with aldrin, dieldrin, or lindane, or by dressing the seed with lindane. Carry-over was however not sufficient to give adequate control in the field so that additional treatment of the transplanted crop was necessary. Root-dip treatment with 0·06 per cent. dieldrin gave good control at transplanting although it sometimes caused a check in growth.

The mortality in field populations of cabbage root fly from natural causes was shown to be about 95 per cent., of which 90 per cent. occurred during the egg stage, the eggs being eaten by predatory beetles. Laboratory studies have shown that more than thirty species of beetle and two species of mite prey on one or more of the immature stages and they could play an important part in reducing the natural populations of the cabbage root fly. Low rates of insecticide treatment were shown to reduce the population of beetles, an effect which lasted for several months, so that there was more damage from cabbage root fly in the treated than in the untreated plots.

A highly efficient method for the control of carrot fly, *Psila rosae* (F.), on carrots was developed by the incorporation of dieldrin by rotavating, prior to sowing, in the top four inches of soil. This control was effective against first and second generation flies and gave protection to carrots grown in the second and third years after treatment. Seed dressings with dieldrin and γBHC also gave good control of first generation flies but it was necessary to apply sprays to control second generation flies in maincrop and late carrots.

Field experiments have been carried out on the effect of dieldrin on the control of carrot fly and its larvae on parsnips. Spacing experiments showed that the percentage of roots attacked and the severity of the attack of the larvae was less on closely spaced than on widely spaced plants.

The biology and control of the lettuce root aphid, *Pemphigus bursarius* (L.), have been studied. Fifty per cent. endrin as a seed dressing gave good control, particularly if it was followed with a spray of 0·2 per cent. endrin or diazinon soon after the plants had been singled. The pest can also be effectively controlled by incorporating endrin, thimet or diazinon in the soil prior to sowing. Certain weeds have been found to be alternative host plants of the lettuce root aphid.

Investigations have been carried out on the cumulative effect of the temperatures occurring under different soil conditions on the development of pea moth, *Laspeyresia nigricana* Steph., larvae from different sources. Prediction of the date of emergence would enable the crop to be sprayed with DDT emulsion at the proper time for the control of the pest.

A study of the biology and control of the carrot-willow aphid, *Cavariella aegopodii* (Scop.), has been started and it has been demonstrated that this insect can seriously reduce crop yield.

A sensitive method of determining the persistence of insecticidal residues in the soil, using adults of *Drosophila melanogaster* Mg. as the test insect, has been developed and a special piece of apparatus designed and constructed for the work.

Pest Infestation Laboratory

Biology

Long-term experiments on population changes of insects in grain are in progress involving the grain weevil, *Sitophilus granarius* (L.); the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.); the Australian spider beetle, *Ptinus tectus* Boield.; and the fur beetle, *Attagenus pellio* (L.). This experimental work is supported by taxonomic studies on the insects and mites concerned.

The effect of low oxygen tensions on insects is also being studied to help in evaluating hermetic storage as a method of keeping grain safely for prolonged periods.

Insecticides

The normal variation in resistance of stored-product insects to insecticides has been studied for many years; recently attention has been devoted to the possibility of insecticidal resistance developing in the grain weevil, *Sitophilus granarius* (L.), towards pyrethrum and in the rice weevil, *Sitophilus oryzae* (L.), towards lindane.

The value of a number of insecticides formulated as wettable powders has been studied and the effect of insecticides on the germination of treated seed stocks has also been worked on in collaboration with the Official Seed Testing Station at Cambridge.

The flour mite, *Acarus siro* L., is being used as a test organism in screening potential acaricides and in determining the factors affecting toxicity.

Field work is also undertaken at home and abroad on such subjects as the control of infestation in groundnuts and cocoa, of insects in flour mills and warehouses, and of cockroaches and ants in industrial premises and institutions.

Fumigants

Studies have been made on the penetration of fumigants into packages and their distribution through bulks of material or spaces by following the changes in gas-concentration.

Data have also been collected on the toxicity of fumigants to insect species in terms of gas-concentrations and exposure times.

A special study is being made of problems associated with the direct biological assessment of the amount of any small survival of insects after a fumigation.

Biochemistry

Studies have been made of the nature and significance of the contamination of cereal and dairy products by DDT, γ–BHC and fumigants such as methyl bromide.

By the use of radioactive insecticides such as γ–BHC, dieldrin and various analogues it has been shown that resistance in houseflies and mosquitos is due neither to failure of the insecticide to penetrate the cuticle, nor to the insect's ability to excrete or detoxify the insecticide sufficiently fast.

Biochemical work has included the effects of insecticides on the metabolism of acetylcholine *in vitro* and *in vivo*, carbohydrate oxidation, and phosphorus metabolism, especially where these have appeared to differ from the corresponding systems in vertebrates.

Overseas Liaison

The Tropical Liaison Department of the Laboratory aims to promote improvements in the handling and storage of produce in the British Colonial and Commonwealth territories and disseminates relevant information to overseas and U.K authorities. Experimental work, either in the laboratory or on a field scale, is undertaken to elucidate specific aspects of problems confronting these territories.

Scottish Horticultural Research Institute

Entomological work is largely concerned with studies of vectors of plant virus diseases.

During 1959 it was established that the nematode *Xiphinema diversicaudatum* Micol. is a vector of the soil-borne arabis mosaic virus.

Experiments with *Amphorophora rubi* (Kalt.), the principal vector of many virus diseases of the cultivated raspberry, have shown that Aphids acquire viruses after feeding for 30 min. or longer on infected plants. Up to 4 hr., infectivity increases with length of acquisition feed, but Aphids transferred to healthy plants lose infectivity in 4–5 hr. Infective Aphids are able to transmit virus to healthy plants in 5 min. feeding periods.

Studies on the spread of aphid-borne viruses have been made by exposing successive batches of runnerless *Fragaria vesca* L. plants to infection spreading from diseased plants of Cambridge Favourite strawberry. More spread of virus occurs in September and October than in July and August. This seems related to fluctuations in the populations of the strawberry aphid, *Pentatrichopus fragaefolii* Ckll. which, in eastern Scotland, reach peak levels in early autumn.

The relationship between phyllody and virescence of clover and other weed plants, and outbreaks of green petal disease in strawberry has been examined. *Euscelis plebeius* (Fall.), was the commonest leafhopper collected in areas where clover phyllody occurred and it transmitted the virus to red clover in glasshouse experiments.

Experiments on the transmission of potato leaf roll virus from infected to healthy *Physalis floridana* Ryd. plants by *Myzus persicae* (Sulz.), have shown that there is a delay in the development of infectivity of Aphids that have fed for less than 24 hr. on infected plants. Tests with single Aphids given acquisition feeds of increasing duration on diseased plants showed that both persistence of infectivity and the frequency of transmission by infective insects varied directly with the length of the acquisition feed. Virus strains which caused mild or severe symptoms in *P. floridana* plants differed in the ease with which they were transmitted by *M. persicae*. Plants already infected with the avirulent strain did not develop additional symptoms after being infested with Aphids carrying the virulent strain, but Aphids were able to acquire and transmit both strains.

A technique was devised for injecting Aphids with the haemolymph of Aphids which had fed on plants infected with potato leaf roll or beet yellow-net viruses. Such Aphids were able to transmit the virus to test plants up to 20 days after injection, and there was no indication that the virus multiplied in the bodies of Aphids.

Surveys of the infestation of potato crops by Aphids are made regularly and the populations of parasites and predators are also assessed. Work during the winter of 1955–56 confirmed that brassica crops, particularly spring cabbage and cabbage grown for seed, are the main overwintering hosts for *M. persicae* in Eastern Scotland. Attempts have been made to control these overwintering populations with systemic organo-phosphorus insecticides.

Aspects of virus diseases of swede and turnip transmitted by flea beetles have been studied.

A.R.C. Unit of Insect Physiology

The Unit was established in 1943 and its objective is to provide fundamental knowledge on the physiology of insects which is likely to prove of value in the agricultural field.

The factors concerned in host selection and host alternation by Aphids are being studied. The research deals with the colonisation of different species of plants and different parts of a given plant and with the effects of galling and of virus diseases. It has been established that the nutritional value of the phloem sap of plants on which Aphids feed varies greatly with the physiological state of the plant. This variation is reflected in the feeding preferences of Aphids, that is, in their distribution on the plant, and in their rate of multiplication. A technique has been developed for direct sampling of the phloem sap by cutting the Aphid away from its mouth parts and leaving them embedded in the plant; under these conditions phloem sap continues to exude from the stump of the mouth parts. In this way the first direct study of aphid nutrition was carried out on the willow aphid *Tuberolachnus salignus* Gmel.

It was observed in the field that the migratory aphids, *Aphis fabae*, *Myzus persicae*, and *Brevicoryne brassicae* (L.) alight indiscriminately on all hosts and even from suitable hosts most of them take off again. This intense locomotor excitation is highly conducive to the dissemination of plant viruses.

Using various plants, the absorption, translocation and persistence of certain organo-phosphorus insecticides, fluoroacetate and fluoroacetamide are being studied. This information is being related to the insecticidal action of these compounds on phytophagous insects, parasites and predators and to their phytotoxic effects.

The properties of the insect cuticle and egg shell, with special reference to waterproofing and respiration, have been the subject of detailed study. These properties determine both the survival of the insect in the dry terrestrial environment in which it lives, and the penetration of insecticides. The knowledge gained has been used as a basis for studying the entry of poisons into the egg of the cabbage butterfly, *Pieris brassicae* (L.). Studies are also in progress on the mechanisms of absorption in the alimentary canal of the locust and on the uptake of nutrients by the ganglia of the cockroach, which may have a close bearing on the entry of insecticides.

It was found that the waterproofing of the cuticle is dependent upon a layer of wax deposited on the surface, and this layer is protected by another, termed the " cement layer," poured out over its surface from the dermal glands. Furthermore, there is a secondary thin layer of wax which lies outside the cement layer which adds greatly to the efficiency of the waterproofing system. In spite of this, the impermeable layer is readily injured if the insect moves in contact with fine dusts or if it burrows in the soil. Insects abraded in this way lose water very rapidly when they are exposed to dry conditions and they show an increased sensitivity to insecticides applied to the surface of the body.

At King's College, Newcastle, studies on population ecology are being pursued, notably on the garden chafer, *Phyllopertha horticola* (L.) on Tipulids and on slugs.

A.R.C. Virus Research Unit

The work of the Unit is concerned mainly with the investigation of viruses of plants, insects and bacteria and the diseases which they cause. Experiments are also carried out on the insect vectors of plant viruses.

During studies on viruses affecting insects of agricultural importance, a new virus was isolated from the leather jacket, the larva of the crane fly or daddy-long-legs, *Tipula paludosa* Mg. Other important viruses have been isolated from caterpillars of the white butterflies, *Pieris brassicae* and *P. rapae* (L.), of the winter moth, *Operophtera brumata* (L.), of the pine sawfly, *Neodiprion sertifer* (Geoffr.), the pine looper, *Bupalus piniarius* (L.), and the clothes moth, *Tineola bisselliella* (Humm.). Arising out of these studies is the possibility of using the viruses obtained in this way for the control of agricultural or economic pests, and considerable success has been achieved already against the pine sawfly in various places.

In collaboration with entomologists in California, a virus affecting the citrus red spider has been isolated. This is the first record of a virus disease in the Arachnida.

The method of multiplication of insect viruses and their shape and general anatomy are being studied by means of new staining techniques for electron microscopy. Cross-transmission of an insect virus between different orders of insects has been achieved for the first time, and this, combined with experiments to stimulate viruses latent in insects, has led to the discovery of new viruses in hitherto unrecorded hosts.

Wye College, University of London

Department of Hop Research

The most serious insect pests of hops in England are the hop aphis, *Phorodon humuli* (Schr.), and the hop red spider mite, *Tetranychus urticae*. Both pests are controlled by systemic organo-phosphorus insecticides; the compound most widely used at first was schradan but at present dimefox and demeton methyl are in common use.

These systemic compounds are markedly superior to the contact insecticides previously used, in terms of control achieved and resulting crop yield. Evidence exists which suggests that dimefox, (bis(dimethylamino)fluorophosphine oxide), may increase yields to a greater extent than can be attributed directly to its insecticidal action.

JAMAICA

REVIEW OF WORK DONE IN THE ENTOMOLOGY DIVISION OF THE MINISTRY OF AGRICULTURE AND LANDS

The principal pests of the more important crops in Jamaica during the period 1954 to 1959 are dealt with very briefly below.

Bananas

The banana weevil, *Cosmopolites sordidus* (Germ.), continued to be an important pest. Excellent control has been obtained with applications of a dust consisting of 4 per cent. dieldrin (50 per cent. wettable powder) in gypsum. In some areas, however, the farmers still rely on biological control with the Histerid *Plaesius javanus* Erichs., but without great success.

Coconuts

The scale insect *Aspidiotus destructor* Sign. attacked palms severely in most of the coconut-growing areas during 1957 and 1958. In an effort to control this pest, a number of species of Coccinellids, including *Azya trinitatis* Mshl. and *Cryptognatha nodiceps* Mshl., were imported from Trinidad and distributed in the more heavily infested areas. A few specimens of these two species were seen at the end of 1959 in two of the localities in which liberations had been made but it is not known yet to what extent they have established themselves. A decrease in the incidence of *A. destructor* has taken place but this may well have been on account of the activity of the local species of Encyrtids (*Aphytis* spp.) and the Coccinellid predator *Chilocorus cacti* (L.).

Sugar Cane

An infestation of the West Indian cane fly, *Saccharosydne saccharivora* (Westw.), occurred during the period under review and importations were made of an egg predator, *Tytthus mundulus* (Bredd.) (Miridae), from Hawaii and of an adult and nymphal parasite, *Pseudogonatopus* sp. (Bethylidae), from South Trinidad. Neither has been recovered, possibly because ecological conditions may be unfavourable. In a survey in 1958, 95 per cent. of the adults of the Delphacid were found to be parasitised by local species of Stylopids. Insecticides have afforded satisfactory control.

The moth borer *Diatraea saccharalis* (F.) was present also in the cane fields but hygienic methods and natural enemies kept the pest within reasonable limits.

Maize

The fall army worm, *Laphygma frugiperda* (S. & A.), has been troublesome throughout the quinquennium and the looper caterpillar or guinea-grass moth, *Mocis repanda* (F.), is also an important pest in the fall. Various insecticides, of which DDT seems to be the most promising, have been tested against these pests; endrin and malathion have also been successfully used.

Cacao

The fiddler beetles, *Prepodes* spp. and *Pachnaeus* spp., are important pests of cacao. The grubs burrow into the soil and attack the roots of the cacao, in severe cases completely girdling the principal roots and causing the sap to cease flowing. In the case of young plants or plants with a defective root system death soon follows. The recommendation for a fully mature cacao or citrus tree with a canopy of about 4 ft. radius is to use Dieldrex 15 (one part in 100 with water) of which a full gallon may be required to cover the surface of the soil beneath the canopy and for about one foot beyond. A tree about four years old may be adequately treated with about two quarts according to the size of the canopy. For treatment of nursery stock or for spraying soil around young plants the recommended treatment is 2lb. of a 50 per cent. dieldrin wettable powder in 100 gallons of water.

Citrus

The soil treatment for fiddler beetles with dieldrin has been detailed above; it was successfully used in the case of citrus.

Sporadic outbreaks of citrus black fly, *Aleurocanthus woglumi* Ashby, have occurred during the period under review. In most areas the Encyrtid *Eretmocerus serius* Silv. was fairly effective in controlling the pest but satisfactory results were also obtained with malathion plus oil. A fruit-piercing moth, *Gonodonta* sp., was found attacking the fruits and some preliminary work on control measures has been undertaken.

Other Crops

The control of pests of cotton, in particular cotton stainers, *Dysdercus* spp., was studied on trial plots and endrin proved to be the most effective insecticide tested.

The leaf miner, *Leucoptera coffeella* (Guér.), commonly occurring on coffee can be controlled with endrin. The green scale, *Coccus viridis* (Green), was also frequently found on coffee, control being effected with white oil or malathion.

A study of the pineapple weevil, *Metamasius ritchiei* Mshl., indicated that this insect seems to require high atmospheric humidity and consequently prefers an environment of dense vegetation.

KENYA

1. REVIEW OF ENTOMOLOGICAL WORK OF THE DEPARTMENT OF AGRICULTURE

The work of the entomological section of the Department of Agriculture is concerned with insect pests of crops both in the field and during storage. Insects attacking trees and timber are the concern of the Forest Department and those attacking man and animals are dealt with by the Medical and Veterinary Departments respectively.

The Agricultural Entomological staff at the end of 1959 consisted of eight entomologists plus two more seconded from the Maize Marketing Board for stored products work.

Laboratories are situated at Nairobi (Headquarters), Ruiru (Coffee Station) and in the provinces at Kibos (Nyanza), Nakuru (Rift Valley) and Matuga (Coast). A Stored Products entomologist is also stationed in the docks at Mombasa.

CROP PESTS AND THEIR CONTROL

Pests of Coffee

Since the last review in 1954 there have been important changes in the status of the various coffee pests. This is probably due in part to the more intensive methods of coffee culture now being used and in part to the extensive use of insecticides.

Leaf Miners—Leucoptera meyricki *Ghesq. and* L. caffeina *Washb.*

These are now the most important pests. The actual area of leaf destroyed is not usually large but the presence of a mine causes premature fall of the entire leaf, especially in unshaded coffee. When leaf miners came into prominence, work was naturally concentrated on insecticidal control. Parathion, methyl parathion or diazinon are the insecticides now used. Research is in progress on the parasite complex. Twenty species of Hymenoptera have been recovered up to date including at least one undescribed species.

Antestia—Antestiopsis lineaticollis (*Stål.*)

This is still a major pest. Malathion or methyl parathion are most commonly used for its control in European areas, though a few planters use DDT or pyrethrum.

In African areas a method has been developed using a spray of 0·006 per cent. pyrethrum on to the foliage and a little 5 per cent. DDT dust on to the trunk of the tree. The spray causes a high initial knockdown. The dust prevents any bugs which survive their initial paralysis from climbing back and recovering completely.

Thrips—Diarthrothrips coffeae *Williams*

There have been no serious outbreaks during the period under review. This is believed to be due, at any rate in part, to the widespread use of mulch in recent years. Counts of mulched and unmulched plots in cultivation trials have shown that mulch greatly reduces thrips populations.

Lace Bug—Habrochila ghesquierei *Schout.*

This Tingid was noted for the first time east of the Great Rift Valley in 1956. It has now spread throughout the main coffee areas and has caused considerable damage. Fortunately its mirid predator, *Stethoconus* sp., appeared at the same time as the Tingid and normally exerts adequate control. Two sprays at an interval of 17–21 days are needed to control this pest. Parathion, malathion or methyl parathion are the chemicals most commonly used.

Mealy Bug—Planococcus kenyae (*Le Pelley*)

Banding tree trunks with 1 per cent. dieldrin has given efficient control of the ant *Pheidole punctulata* Mayr. and this has reduced the mealy bugs to the status of a minor pest. Spot spraying of suckers with diazinon is used to clear up stubborn infestations.

Leaf-eating Caterpillars

The most important of these are the leaf skeletoniser, *Leucolema dohertyi* (Warr.), the stinging caterpillar, *Parasa vivida* Wlk., the jelly grub, *Niphadolepis alianta* Karsch., and west of the Rift Valley, the tailed caterpillar, *Epicampoptera andersoni* (Tams.). Lead arsenate is normally used for their control. Peasant farmers use malathion or pyrethrum. These caterpillars have caused much damage during the period under review, especially in the years 1956 and 1957. *Leucolema* had not previously been recorded in the main East Rift coffee areas.

White Borer—Anthores leuconotus *Pasc.*

The control measures developed in Tanganyika for this pest (spraying the lowest 18 inches of the coffee tree trunk with 0.5 per cent. dieldrin) have proved highly successful in Kenya. The beetle is now rare in areas previously heavily infested. The present recommendation is to re-spray every two years.

Yellow-headed Borer—Dirphya nigricornis *Ol.*

Previous reports of *D. princeps* Jord. attacking coffee in the East Rift appear to be incorrect, only *D. nigricornis* has been collected in recent years and of this there have been a few severe but localised outbreaks during the last five years. The fumigant EDCT or 0.2 per cent. dieldrin is injected into each tunnel if control measures are needed.

Tip Borer—Eucosma nereidopa *Meyr.*

The caterpillar of this moth has done severe damage boring in the tips of suckers wanted as verticals for a new cycle. It is only serious in high altitude coffee.

Spraying the trunks of shade trees with 2 per cent. DDT gives promise of being an effective indirect control measure. This is a favourite daytime resting site for the moths.

Pests of Cereals

Barley Fly—Hylemyia arambourgi *Seguy*

This was first recorded in 1952 but it did not become a serious pest until 1954.

The eggs are laid on the soil surface near barley seedlings or on the barley stems. The maggot burrows down into the central shoot which dies, the seedling then tillers or dies but the new tiller may be infested. In a heavy infestation many plants are killed while others remain stunted and flattened. The pupa occurs in the soil. The adults can be found in areas where barley is not grown and larvae of similar appearance have been found in various grasses. The pest also occurs in some varieties of wheat. Seed dressings of aldrin, dieldrin, endrin, heptachlor and chlordane give varying degrees of protection, the two better materials being dieldrin and heptachlor. Dieldrin is used at 5 oz. active ingredient to 100 lb. of seed and is the standard remedy as heptachlor is not yet available on the local market. Spraying of the young crop is more expensive than seed dressing, and as it must be timed to coincide with an infestation, it cannot be recommended although it can be effective.

Sorghum Shoot Fly—Atherigona indica infuscata *Emd.*

Sorghum shoot fly occurs throughout the Colony but is normally not controlled. Sprays of endrin or DDT are effective as well as the BHC/DDT dust mixture developed in Tanganyika.

Maize Stem Borers

Five stem borers occur in maize. *Sesamia cretica* Hmps. so far has been recorded in the extreme northwest, *S. calamistis* Hmps. is widespread but not a serious pest while the third Agrotid, *Busseola fusca* (Fuller), is by far the most serious stem borer in high altitude maize. At about 4,000 feet *Chilo zonellus* Swinh. occurs; at this altitude both these borers can cause serious damage. *Busseola* does not occur at the Coast, but is replaced by *Chilotraea argyrolepia* (Hmps.).

B. fusca does not appear to have been a serious pest during the period under review. It is controlled annually by many European farmers but few African peasants apply dusts or sprays. Where labour is available the 1 per cent. DDT applied down the funnel of the young plant is still recommended. In dry weather a dilute DDT solution may be preferred. Boom spraying with 1 lb. of DDT per acre is commonly employed though endrin has been found very satisfactory.

Since *C. zonellus* attacks the maize by boring directly into the stem, funnel treatments do not give a high degree of control. Overall sprays of DDT or endrin have given increases of 34 per cent. in the Coast province.

Black Wheat Beetle—Heteronychus spp.

Seed dressings of γ BHC or of aldrin on wheat have reduced damage due to this pest to low proportions and yield increases of up to 2½ times have been recorded.

Nematocerus Weevil—Nematocerus *spp.*

This flightless weevil causes severe damage to barley and wheat in certain areas. The larva appears to be fairly resistant to insecticides though heavy soil applications have yet to be tried. The adult can be baited with BHC baits which are very effective. The pest, which also damages the roots of tea seedlings, has been eliminated from tea nurseries by continued baiting of the adults.

Pests of Cotton

Cotton is grown in two main areas, one in Nyanza towards the Uganda border and the lake shore, and the other in the Coast province in the coastal belt and on the Tana river. On the latter, the irrigation scheme at Galole is sprayed by aircraft using endrin. Elsewhere little or nothing is done by way of control except in experiments.

In Nyanza 3:10:0 cotton dust is used in the drier areas. Yields are substantially increased up to 140 per cent. while the amount of stained cotton is much less (*e.g.* 20 per cent. as against 50 per cent. for no treatment). Near the Uganda border, where stainer damage is less, DDT is applied as a spray against bollworm and Mirids. Increases of 117 per cent. have been recorded.

Regular spraying in the Coast province increased the value of the crop by 173/– per acre in 1959; treated plots yielded nearly twice as much as those which had remained untreated.

Pests of Coconut

The Coreid bug, *Pseudotheraptus wayi* Brown, which feeds on coconut inflorescences causing premature nutfall, has been investigated in Kenya from the point of view of control by peasant growers; the requirements of plantation growers are being met by tractor-drawn machines and aerial spraying in Zanzibar and Tanganyika. An attempt was made to encourage the ant *Oecophylla* which preys on *Pseudotheraptus* but this was not successful. More recently, an attempt at biological control by releasing egg parasites, collected locally, and another species from Zanzibar has been made, but results are not yet available.

Bio-assay work, designed to find a suitable spray for hand application, has shown that dieldrin is about five times as toxic as DDT. Pyrethrum is relatively ineffective. Systemic insecticides are disappointing. A small hand sprayer has been developed by Long Ashton Research Station which will hold a pint of dieldrin spray under pressure and which can be carried on the belt of a coconut climber. This can be discharged into the crown of the palm and then brought down empty for re-charging. By the use of such a sprayer the irregularly shaped groups of palms can be effectively dealt with: spraying them by aircraft or by ground machines would be very expensive.

As elsewhere, control of *Pseudotheraptus* gives a temporary increase in yield which is not sustained and it would appear that other factors limit coconut production.

Pests of Other Crops

A certain amount of work has been done on the control of horticultural pests such as citrus bud mite, red spider mite, citrus rust mite, red scale, citrus black fly and false codling moth in citrus. Materials used were various miticides, white oil, malathion, diazinon and endrin. So far good control of citrus bud mite, *Aceria sheldoni* (Ewing), has been achieved by the use of 0·03 per cent. chlorobenzilate: the same material kills red spider mite, *Eutetranychus banksi* (McG.) and rust mite, *Phyllocoptruta oleivorus* (Ashm.). Only partial control of false codling moth, *Argyroploce leucotreta* Meyr., has been achieved by the use of endrin and it would appear that reinfestation from outside sources takes place.

Good control of pineapple mealybug, *Dysmicoccus brevipes* (Ckll.), has been achieved by dipping planting material for five minutes in 0·05 per cent. diazinon or 0·1 per cent. malathion. Control of the attendant ants was not satisfactory.

A heavy outbreak of the Lymantriid, *Argyrostagme niobe* (Weym.), occurred in wattle in 1956–57 and this proved difficult to control by insecticides. Eventually the infestation died out partly through the efforts of predators, but mainly through a polyhedral wilt disease.

In pyrethrum, heavy attacks of *Thrips* occurred from 1957 onwards and while good control was achieved by spraying with DDT or dieldrin this was sometimes followed by outbreaks of red spider mite, *Tetranychus ludeni* Zacher, and spraying of Metasystox was necessary. A comprehensive study of pyrethrum pests is now being planned.

Satisfactory termite control has been achieved by the use of aldrin and dieldrin poured into nests or by dipping planting material in 0·1 per cent. dieldrin; the latter treatment has doubled the yield in sugar cane.

Biological Control

Control of *Orthezia insignis* Browne by *Hyperaspis jocosa* (Muls.) continues to be satisfactory, whilst the Cochineal insect, *Dactylopius tomentosus* (Lam.), is giving good control of prickly pear, particularly of the species believed to be *Opuntia dilleni.*

The Lantana fly, *Ophiomyia lantanae* (Frogg.), has been introduced and is now widespread in the Colony. The lacebug, *Teleonemia scrupulosa* Stål, is achieving some control of *Lantana* in the Coast Province, but is less satisfactory elsewhere. The parasite *Eretmocerus serius* Silv. of the citrus black fly, *Aleurocanthus woglumi* Ashby, was successfully introduced from the Seychelles in 1959.

PESTS OF STORED PRODUCTS

Stored products work has been largely concerned with maize storage. Heavy losses have occurred in farm storage and again in the large reserves maintained in central stores for famine relief. Work has consisted of (1) protection of maize on the cob in cribs, (2) treatment of buildings with persistent insecticides, (3) dusting and spraying the outside of bags, (4) methyl bromide fumigation and (5) treatment of bagged maize by the addition of insecticidal dusts.

Maize Crib Work

The standard practice is to dust every 9 cubic feet of cobs with 8 oz. of 0·5 per cent. γ BHC and this has been found to give good results on farms. The use of this dust leaves the sides of the crib, exposed to the air, without much protection, and attempts were made to provide a barrier of grass thatch, napier grass, hessian and hessian sprayed with BHC. The latter has proved to be very effective.

Treatment of Buildings

Early work on insecticidal resins has not been followed up due to pressure of work, though some showed promise. At present buildings are sprayed with a mixture of BHC and DDT. Preliminary tests with malathion have not been impressive under the hot conditions pertaining in Mombasa.

Treatment of Bagged Maize

Experiments have shown that 1 per cent. lindane dusted at 2 oz. per bag of maize gave no appreciable protection.

Methyl Bromide Fumigation

Methyl bromide fumigation is now extensively used in Kenya. Alleged failures to kill *Tribolium castaneum* (Hbst.) in Mombasa were investigated and it is believed that rapid re-infestation takes place after the stack is unsheeted. A large building containing about 100,000 bags of maize was rendered gas-tight and it was successfully fumigated without the use of re-circulating apparatus.

A new technique was developed whereby fumigation sheets are left in *situ* after fumigation and thus act as a physical barrier to re-infestation.

Treatment of Bagged Maize by the Addition of Insecticides

In the Nairobi area experiments in the past showed that 1 p.p.m. of lindane gave adequate protection against insect pests. More recently it has been shown that this is ineffective in the hotter parts of the Colony. Preliminary work suggests that malathion at 8 p.p.m. is effective, and further work with this and lindane is being done. The use of pyrethrins with piperonyl butoxide has given good results.

Trogoderma granarium Everts

This pest occurs in incoming cargoes, and routine inspections, followed by fumigation when necessary, have had to be instituted. A study of the life history in the laboratory has been undertaken so that developmental rates under Kenya conditions are known. These would be of value if the pest was able to establish itself in the territory; it is already established in Tanganyika.

OPERATION OF THE PLANT PROTECTION ORDINANCE

Part of the Plant Protection Ordinance is administered by the Senior Entomologist and is concerned with the regulation of the import of planting material and with the issue of export certificates. Uniformity of action in the East African territories of Kenya, Uganda, Tanganyika and Zanzibar has been achieved by the Standing Technical Committee on Plant Imports and Exports under the Chairmanship of Dr. H. H. Storey of the East African Agricultural and Forest Research Organization. The entomologists and plant pathologists of these territories are members of the Committee and the pooling of information which has accrued has been most valuable. A card index system has been introduced which gives the stipulated conditions for importations; this is based on local advice together with conditions laid down by the Inter-African Phytosanitary Commission. This card index system has reduced the amount of work. Import permits are no longer required for some seeds. Fumigations with HCN are now infrequently carried out. Fresh fruit from Asia is no longer permitted and its fumigation is thus no longer required.

The International Phytosanitary Certificate of the 1951 Convention has been introduced in a trilingual form—English, French and German.

TAXONOMY

A special study of the mealy bugs (*Coccoidea: Pseudococcidae*) from South Africa south of the Sahara is being undertaken by Dr. de Lotto, in collaboration with Dr. D. J. Williams of the Commonwealth Institute of Entomology, with the aid of funds made available under the Colonial Development and Welfare Act. Two papers redescribing all species recorded or described by James from East Africa and by Brain from South Africa have already been published by de Lotto. This has involved the study of a large amount of material from East and South Africa in the collections at the Scott Agricultural Laboratories. Many new species have been found and a paper giving descriptions of the first thirty of these is in the press.

At the same time a revision of other Coccid genera containing species of prominent economic importance, such as *Coccus* and *Saissetia*, has been carried out. A survey of the green scales of coffee in East Africa revealed four new species which have been described.

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[1] In addition G. de Lotto has published 12 other papers, comprising some 86 pages, on the Coccidae from Africa, chiefly East Africa, in a variety of journals.

2. ENTOMOLOGICAL WORK IN THE FOREST DEPARTMENT

The staff consists of an entomologist, one forester (entomology) and four native rangers.

Research was concentrated on two main problems, the results obtained being summarized below:—

Biology and Control of *Oemida gahani* Dist. (CERAMBYCIDAE)

This dead wood borer is the major forest pest in Kenya. Found commonly in highland indigenous forest, where it attacks dead wood of at least 75 tree species, it is also attracted to wounds on exotic Cypress species through which it gains access to the central heartwood core. Its larval borings often render this timber unsaleable, though without affecting the health or growth of the tree.

It has been established that large wounds such as those produced by game, are more attractive for oviposition than small pruning scars. In areas where the incidence of the pest is high and game damage slight, entry through such scars often occurs however. The greatest damage is found in plantations in which logs and stumps of the most susceptible indigenous trees remain as breeding sites and foci of attack.

Where pupation occurs in the living sapwood the adult beetles fail to emerge from the wood: successful emergences occur through the dead wood of scars. Only one other species, the indigenous Cedar, *Juniperus procera*, is attacked through pruning scars and has heartwood damaged in the living tree. Exotic species of Pine are immune from attack, apart from the old dry dead wood of exposed wounds. The resin of living wood and that freshly exuded from wounds is lethal to the larvae.

This pest is found in the majority of forest areas from 4000 feet to over 9000 feet. Climatic conditions at the Coast are unfavourable for its development.

There is no evidence of effective natural control by predators or parasites, though a few Braconid and Clerid spp. have been found. Larvae are occasionally killed by disease, probably caused by a virus.

The main methods of control so far developed are:—

(a) Improved plantation hygiene, which involves the clearing and burning of all indigenous logs and stumps before planting exotic spp.,

(b) prevention of game damage by game control, fencing and ditching,

(c) early and frequent pruning of Cypress spp. to keep the size of scars to a minimum and to facilitate their rapid occlusion,

(d) treatment of pruning scars with chemicals to prevent entry of larvae in older plantations where clearing of indigenous stumps is impractical.

(e) separating Cypress plantations from natural forest by cleared strips of Pine plantations, to prevent spread of beetles from the latter to the former.

The Economic Importance and Control of Ambrosia Beetles

More than 40 indigenous tree species are attacked after felling and over 30 different beetle species have been collected, but economic losses are generally slight. Damage occurs over a wide climatic and altitude range, from the Coast to over 9000 feet. It is heaviest however, in the warmer, humid areas below 7000 feet, particularly near Lake Victoria, Mt. Kenya and the Coast. Nine indigenous tree species are attacked while still living, though only unhealthy or over-mature trees are so affected. Attack of exotic plantation species, such as Eucalyptus, Pine and Cypress occurs very infrequently.

A comparison of BHC and dieldrin sprays in oil and water demonstrated the greater efficiency of the former in preventing attack of logs during periods of heavy rainfall. The most effective and cheapest spray treatments, applied at the rate of one gallon per 100 sq. ft. of log surface were (a) a powder suspension in water containing 2 per cent. γ BHC which gave complete protection for two or three months, and (b) a solution in oil containing 1 per cent. γ BHC which gave complete protection for more than three months.

3. A GENERALISED SUMMARY OF TSETSE AND TRYPANOSOMIASIS CONTROL IN KENYA

By P. E. Glover, P. Napier Bax and E. C. Trump

Department of Veterinary Services, Kenya

At present about one quarter of Kenya's total area is infested by tsetse flies (see map) and animal trypanosomiasis is endemic wherever they occur. All tsetses transmit trypanosomiasis, while *G. palpalis* (R.D.), *G. swynnertoni* Aust. and *G. morsitans* Westw. are the vectors of human sleeping sickness. The different species of fly occupy a wide range of vegetation types—from coastal forest to arid scrub, but do not thrive at altitudes above 6,000 feet so that most of the highlands are fly free. Large numbers of cattle, possibly three quarters of a million, are however, grazed in or near marginal tsetse country and 330,000 doses of trypanocidal drugs were used last year.

Staff

In Kenya the control of tsetse and trypanosomiasis is the responsibility of the Zoological Division of the Department of Veterinary Services. As trypanosomiasis is now to a greater extent a veterinary rather than a medical problem in Kenya, this system has the advantage of providing the fullest degree of liaison between the tsetse control and veterinary staff, particularly as regards policy, and the administration of drugs. Nevertheless, measures against human trypanosomiasis are by no means neglected as there is close collaboration between this section of the Veterinary Department and the Medical Division of Insect-Borne Diseases (Whiteside, 1958b).

The European staff consists of a Chief Zoologist and eight Field Zoologists, nineteen Technical Officers (one Senior Field Officer, four Field Officers and fourteen Assistant Field Officers), one Laboratory Technologist, and one stenographer. The African staff is made up of fifteen Field Assistants, nine clerks, nineteen microscopists, twenty-two truck drivers, six tractor drivers, and about three hundred and fifty " Fly boys."

The Division is also responsible for helminthology and the control of ticks and insect transmitted diseases, but its main effort is directed against the tsetse fly and trypanosomiasis, and the staff referred to are those involved with this latter work.

Two of the Field Zoologists are engaged on full-time research; one, assisted by the Laboratory Technologist, on chemotherapy, drug resistance and immunity, and the other on the practical aspects of tsetse bionomics and their application in the field. A third Field Zoologist is a highly trained ecologist and skilled cartographer while the other five are in charge of control measures and tsetse and trypanosomiasis surveys in the provinces. The Senior Field Officer is engaged on experimental work in testing new drugs both in the laboratory and in the field, whilst at the same time giving advice to farmers on tsetse matters when this is required. The other Technical Officers are in charge of field stations under the Field Zoologists.

SPECIES OF TSETSE

There are eight species of *Glossina* in Kenya. Very briefly the habits are (1) *G. pallidipes* Aust. widely distributed, breeds in thickets, and is active during the daytime; it feeds mainly on bushbuck and pig and also on big game when it is available, such as buffalo, elephant, giraffe, and eland. (2) *G. palpalis* (R. D.), the lake shore fly, lives and breeds in the forest and bush fringing Lake Victoria, and along the rivers running into it; it is active during the day and feeds mainly on crocodiles, monitor lizards, bushbuck and birds. (3) *G. longipennis* Corti is widely spread in the dry scrub country, and breeds under logs, rocks and clumps of bush; it is crepuscular and feeds mainly on rhinoceros, but also on elephant and buffalo. (4) *G. brevipalpis* Newst. lives in riverine bush and fringing lake shore forest and breeds in soft soil in shady places under dense canopy; it is crepuscular and shows preferences for feeding on pig, hippopotamus and rhinoceros. (5) *G. swynnertoni* Aust. is confined to a small area of Masailand and lives in scrub country and hardpan; it breeds under logs and on the edges of clumps of bush and is diurnal, feeding on warthog, bushpig and big game. (6) *G. austeni* Newst., the smallest of all East African tsetse flies, lives in the coastal forests and is never found far from the forest edge; it breeds under logs in shady places and is known to feed on bushpig and forest duiker. (7) *G. morsitans* Westw. is confined to only a small area near Karamoja on the Uganda border, and breeds under logs, in rot holes in trees and in the shade of thickets; it is diurnal and feeds on warthog, bushpig and the larger game animals. (8) *G. fuscipleuris* Aust. lives in dense forest, and breeds in the leaf mould around tree trunks under heavy shade; it also is crepuscular but little is known of its feeding habits as it occurs on only one or two rivers running into Lake Victoria.

METHODS OF CONTROL

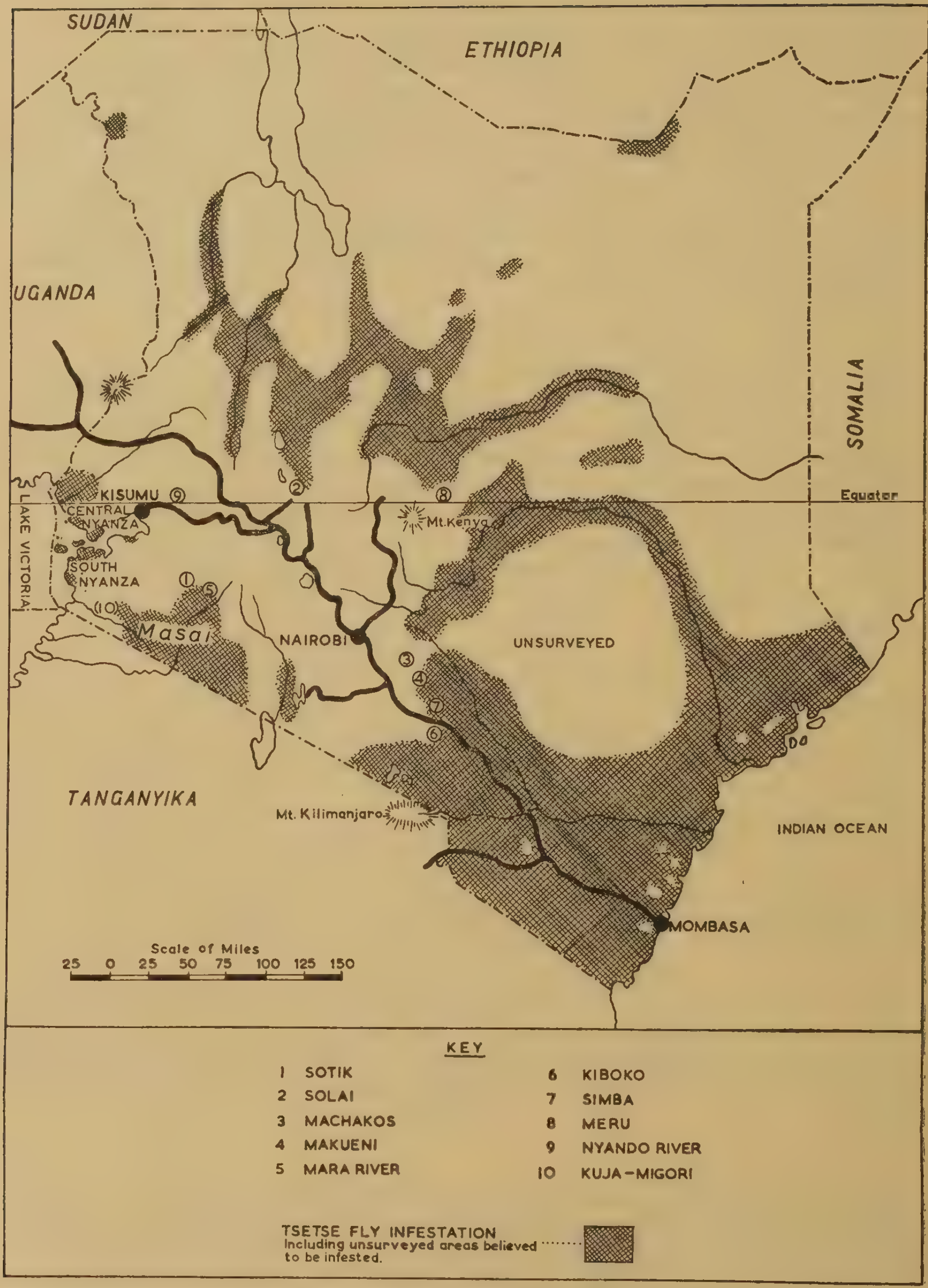
The three main methods of tsetse and trypanosomiasis control in use in this country are:—(1) indirect attack on the fly—bush clearing; (2) direct attack—the application of insecticides to fly in infested bush and (3) attack on the parasite—the use of trypanocidal drugs.

Bush Clearing

The four ways of clearing bush most commonly used are by sheer clearing by hand, discriminative clearing by hand, mechanical clearing and clearing by fire.

Sheer clearing by hand

This method consists of cutting down all trees and bushes by hand, leaving only bare ground or grass. It has been used as an anti-sleeping sickness measure on rivers in Nyanza (Symes and Vane, 1937; Lewis, 1947; Wilson, 1953). It was also used to create a " fly barrier " seventeen miles in length along the Masai-Kipsigis border and the Sotik farming areas. It is the method most often used in settlement schemes where the main object is to prepare the land for crops, for instance at Makueni in the Machakos area, in the Shimba Hills at the coast, in the Lambwe Valley in South Nyanza, and at Giaki in the Meru district. Similarly, European farmers at Sotik, Solai and in the Thika area have cleared bush in this way for the same reasons. This method is laborious and costly, and unless the clearing is planted up with grass or crops the control of regrowth is a serious problem, so that annual


SUDAN
ETHIOPIA
UGANDA
SOMALIA
Equator
KISUMU ⑨
CENTRAL NYANZA
LAKE VICTORIA
SOUTH NYANZA
①
⑤
⑩
Masai
NAIROBI
②
⑧
Mt. Kenya
UNSURVEYED
③
④
⑦
⑥
TANGANYIKA
Mt. Kilimanjaro
INDIAN OCEAN
MOMBASA
Scale of Miles
25 0 25 50 75 100 125 150
KEY
1 SOTIK
2 SOLAI
3 MACHAKOS
4 MAKUENI
5 MARA RIVER
6 KIBOKO
7 SIMBA
8 MERU
9 NYANDO RIVER
10 KUJA-MIGORI
TSETSE FLY INFESTATION Including unsurveyed areas believed to be infested.

maintenance may be very expensive. The initial costs of clearing range from 30/– to 80/– per acre, depending on the density and size of the bush.

Discriminative clearing by hand

This consists of cutting out certain elements of a vegetation community only, for instance the shrubby undergrowth and leaving the tall clean-boled trees, but to be effective it must be based upon an intimate knowledge of the habits of the species of fly concerned. It has not been very extensively used in Kenya although it proved successful in exterminating *G. brevipalpis* from a patch of riverine forest at Kiboko (Annual Report, 1957), and experiments in *G. austeni* infested forest near Kilifi at the coast showed that this fly could be eradicated by merely cutting out the light undergrowth and lianas. Costs for this type of clearing range between 15/– and 30/– per acre.

Mechanical clearing

A considerable amount of clearing with bulldozers has been done in this country (Glover *et al.*, 1959). Two methods were used, " blading " *i.e.* pushing the vegetation out with bulldozers and depositing it in long piles or " windrows " about thirty yards apart, and " chaining," *i.e.*, dragging it out with a heavy ship's anchor chain, slung between two D.8 Caterpillar tractors. Work of this type was undertaken at Makueni, in the Machakos district, where about 3,400 acres of scrub were cleared in 1952; and at Simba and Kiboko about one hundred miles from Nairobi on the way to Mombasa, where about 5,000 acres were cleared between 1952 and 1955. More than 27,000 acres of *Commiphora-Acacia* scrub on the Athi-Tiva Scheme, near Kitui, were cleared in 1955–1956 as an anti-tsetse measure, and at the same time to increase the amount of grazing available to the local tribesmen. In Masailand, on the Mara Ranch, about 4,700 acres of evergreen forest were cleared as an experiment, and to increase the size of the ranch; whilst, in the Lambwe Valley, 1,000 odd acres were cleared in light *Acacia-Balanites* woodland as a " barrier " to prevent the movement of *G. pallidipes* into the settled areas. Over a period of seven years, from 1952 to 1959, 44,900 acres of bush were cleared in this way at an average cost of about 40/–per acre for chaining and blading together; 60/– for " blading " alone, and 25/– for " chaining " alone. Experience has shown that chain clearing is most effective in country with an annual rainfall not exceeding 30 inches, because regrowth in areas of higher rainfall is very profuse.

Clearing by Fire

In some types of country such as the dry *Commiphora-Acacia* scrub in Kitui district, and in some parts of Masailand, repeated burning gradually converts bush country to grassland. In practically all clearing schemes, controlled burning plays an important part in reducing regrowth. Vast areas of Kenya are burnt annually by the natives and this custom plays a significant part in preventing the spread of thicket, and so of tsetse.

The Use of Insecticides

Insecticides were used experimentally in Kenya in 1949 to " de-fly " trains travelling through fly-infested country from Mombasa to Nairobi. For the next four years, various methods were employed with this purpose in view, but never with complete success owing to economic and technical difficulties (Fairclough, 1956).

In 1951 an experiment was started in the Kibigori area of Central Nyanza in an endeavour to exterminate *G. palpalis* from the Nyando river basin, covering some 300 square miles of country in which a human sleeping sickness epidemic had started two years previously. DDT sprays were applied to paths cut through the vegetation on either bank of the rivers with knapsack sprayers. By 1956, about 137 miles of riverine bush had been sprayed and no further *G. palpalis* have been caught anywhere in that area since. This was achieved at a cost of £68 per river mile, as compared with £200 per river mile for bushclearing (Fairclough and Thomson, 1958). In 1955, it was decided to conduct a similar but bigger experiment on the Kuja-Migori river system in South Nyanza, where human sleeping sickness had been endemic for many years. In this case the insecticide used was Dieldrex 15, consisting of an 18·2 per cent. dieldrin emulsion diluted in water to 1·8 per cent. dieldrin. This scheme proved even more successful than the previous one, and by the end of 1959 *G. palpalis* had been exterminated from more than 700 miles of the Kuja and Migori rivers and their tributaries, while only about 150 miles of the upper part of the Migori river system still remained to be treated.

As a result of this second success, it was decided to spray all the rivers, lake shore and islands infested with *G. palpalis* in Nyanza Province, so that by the end of 1959 about 65 miles of the lake shore from the Tanganyika border onwards had also been treated. About 500 miles of lake coastline and 400 miles of river are involved. The scheme will take about 5 years to complete at a cost of roughly £100,000.

The Use of Trypanocidal Drugs

In the early days of Kenya, although sleeping sickness had decimated the human population on the shores and islands of Lake Victoria, the importance of animal trypanosomiasis was obscured by the more pressing need to control the major animal-killing diseases such as rinderpest and East Coast fever (Whiteside, 1958b). In any case, the knowledge and drugs at the disposal of veterinarians at that time were so limited that little could have been done.

However, as far back as 1904 the drug Atoxyl was in use as a remedy for human trypanosomiasis, and later, tartar emetic which was also used for domestic animals (Davey, 1957).

Then in 1920, Bayer 205 was produced, which proved very effective against the two trypanosomes (*T. gambiense* and *T. rhodesiense*) in human beings and also against *T. brucei* in horses and dogs, and against *T. evansi* in camels. But it was not until the 1930s, when the phenanthridium drugs (Phenidium etc.) first appeared, that any real success was gained against the cattle trypanosomes *T. congolense* and *T. vivax* (Davey, 1957). From these drugs dimidium bromide was developed. With this drug it was possible to treat large numbers of cattle simultaneously, but it had the disadvantage of causing liver damage and photosensitization. It has now been superseded by the more modern drugs which are discussed below.

It is convenient to class trypanocides in two main divisions, the curatives which kill the trypanosomes in the blood quickly but do not give any prolonged protection, and the prophylactics which protect animals from infection in areas of light fly infestation for limited periods. Some drugs have a further property in that they are able to overcome infections which have become " resistant " to other drugs and when used in this way they are called " sanatives " (Whiteside, 1958a).

Curative drugs are the type mainly used to treat individual cases of trypanosomiasis in herds. Cattle are only effectively protected by prophylactic drugs where mass treatment and strict supervision is possible, as " resistance " to them easily develops, particularly with incorrect usage, for example, where the interval of treatment is too long, or some of the animals in a herd are underdosed.

The curative drugs in use in Kenya against *T. congolense* and *T. vivax* are homidium, Antrycide methylsulphate, Berenil and the very recent metamidium chloride, while suramin is used to cure *T. brucei* and *T. evansi* infections.

The prophylactic drugs are Antrycide Pro-Salt and Prothidium which are still under trial. Testing of new drugs, particularly prophylactics, proceeds continually. These include the " suraminates "—combinations of various drugs with suramin.

When resistance develops to any particular drug, alternative drugs are sometimes effective but sometimes not. If a " strain " of trypanosome resistant to one drug is not cured by a different one, this strain is said to be " cross-resistant " to the second drug. For instance a strain highly resistant to Antrycide may not be cured by homidium or Berenil, and is then said to be cross-resistant to these two latter drugs. Considerable light has now been thrown on these drug relationships by recent research (Whiteside, 1958b).

Among the curative drugs the only pairs between which infections resistant to one drug appear not to be cross-resistant to the other are homidium and Berenil, and Berenil and metamidium chloride. A curative régime alternating either member of one of these two pairs, say for a year each, or until resistance to one appears, seems to offer considerable possibilities of success in the light of present knowledge.

Among the prophylactic drugs no such pairs have been found. So far the only two prophylactics in general use in Kenya are Antrycide Pro-Salt and Prothidium. Strains of trypanosomes resistant to Pro-Salt can be cured in the early stages by homidium or Berenil at double dosages, 2 mg./kg. and 7 mg./kg. respectively. Berenil will also sometimes cure Prothidium resistance, if this is not too highly developed. But the only really effective " sanative " is metamidium chloride at 2 mg./kg. or higher dosages, which has so far cured practically all resistant strains (Whiteside, 1958a).

TSETSE RESEARCH

Recent research in this field has been directed to discovering what game animals tsetse feed on, where the flies rest, and where they breed (Langridge, in press) and it has been shown that all of them seem to have preferences for feeding on certain animals. As a development of this work, an extract of domestic pig hair and skin scrapings was found to be very attractive to *G. pallidipes*. Treated traps and paths were found to attract up to five times as many flies as the controls. This discovery may well have an application in conjunction with insecticides. Incidentally, traps were found to be a very much more sensitive means of locating the presence of fly than patrols by fly boys, and are cheaper to use.

The resting places of tsetse were found to be on the underside of branches and on the stems and trunks of trees. This information also has proved of practical value in that when insecticides are used they are sprayed on to the stems and undersides of the vegetation.

The combination of measures in use in Kenya against tsetse flies and trypanosomiasis, as described above, are effective, but our research work aims at ever-improving and refining them. Great strides have been made in the development of efficient trypanocidal drugs but these cannot be successfully used if the density of tsetse is too high. Many of the areas infested have only a low rainfall and are ill-supplied with water. Consequently, reclamation schemes are expensive and although they are locally most impressive, and cover many thousands of acres, much tsetse country still remains unreclaimed. It must be emphasised that if the full benefit of these schemes is to be realised, correct methods of land usage must be adopted by the African settlers and this often proves a more serious difficulty than the initial clearance of the fly.

The use of insecticides against *G. palpalis*, the main vector of human sleeping sickness, has been one of the most successful developments and so far the fly has been eradicated from about 1,400 square miles (Glover and Trump, in press). This work is proceeding and aims at the ultimate extermination of *G. palpalis* from Kenya.

Acknowledgements

We wish to thank the Director of Veterinary Services for his kind permission to publish this paper, and all our colleagues for the work which has been done.

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MAURITIUS

REVIEW OF AGRICULTURAL ENTOMOLOGY

ORGANISATION

The Department of Agriculture was until recently the only organisation in Mauritius concerned with pests of agriculture, its work embracing plant inspection and quarantine, advisory and research work upon pests of all crops, as well as recording and building up collections of local insects. In 1953, the Mauritius Sugar Industry Research Institute was created to assume all research and experimentation concerning sugar cane and in 1957 an Entomological Division was established within that Institute and now deals with all matters pertaining to pests of sugar cane. A third organisation, the Mauritius Institute, is a combined museum and public library which although not directly concerned with agriculture is of considerable value to workers in that field owing to the systematic and faunistic work it undertakes upon the insect fauna of the Mascarenes.

Pests of sugar cane

(*a*) *The Stalk borer*

The control of the stalk borer, *Proceras sacchariphagus* Bojer, which is the island's most important sugar cane pest, presents a particularly difficult problem. Insecticidal methods are not practicable while many factors often preclude the cultivation of varieties which show above average resistance or tolerance to the borer. Parasite introduction has therefore been the main approach to the problem of borer control although, as yet, with little success. During the period under review, the following parasites were introduced: *Apanteles diatraeae* Mues. and *Zenillia palpalis* (Aldr.) from Trinidad, *Rhaconotus scirpophagae* Wlkn., *Elasmus zehntneri* Ferrière, *Tetrastichus israeli* (Mani & Kurian) and *Stenobracon nicevillei* Bingh. from India. The first two species have not apparently become established; the results of the other introductions are not yet known.

(*b*) *Leafhoppers*

Two related species of Delphacidae breed upon sugar cane in Mauritius. These are *Perkinsiella saccharicida* Kirk. and *Dicranotropis muiri* Kirk. Neither species causes direct injury of consequence to sugar cane but the former is a vector of Fiji disease of sugar cane, now present in Madagascar, and is therefore of considerable potential importance. An ecological study of the Delphacidae found on sugar cane was accordingly made to provide data upon their distribution, abundance and natural enemies. The results of this work have been published (Williams, 1957).

In connection with the above, the Mirid, *Tytthus mundulus* (Bredd.), was introduced into Mauritius from Hawaii in 1956–57 and is now firmly established and widely dispersed. This Mirid is a well-known predator of Delphacid eggs and played an important role in reducing the abundance of *P. saccharicida* in Hawaii early in this century.

(*c*) *Experiments with soil insecticides*

Experiments were begun in 1956 with chlordane and aldrin to determine their efficacy as soil insecticides in cane fields. The primary object was to discover if a cheap and simple method of preventing infestations of white grub, *Clemora smithi* (Arr.), could be evolved upon the basis of the prolonged residual effect of these insecticides when incorporated in soils. Results of experiments to date show that both insecticides when applied to the furrows at planting can prevent grub infestation to a marked extent for a period of three years but there appears to be little margin of safety between insecticidal doses and those which effect cane growth.

Pests of the Pigeon Pea

The introduction of parasites to control *Maruca testulalis* (Geyer) and *Etiella zinckenella* (Treitschke), the two most important pests of the pigeon pea, *Cajanus cajan* (L.) in Mauritius, was continued. The following species were introduced from Trinidad and Puerto Rico: *Chelonus busckiella*, in 1956, *Phanerotoma bennetti* Mues. in 1958 and *Heterospilus etiellae* Rohw. in 1959. None of these have yet been recovered. Of species introduced previously, *Eiphosoma annulatum* Cress. and *Bracon cajani* Mues. are well established and have been found to be abundant in several localities in recent years.

Fruit Flies

The following species of Trypetid fruit flies occur in Mauritius: *Dacus zonatus* (Saund.), *D. cucurbitae* Coq., *D. ciliatus* Lw., *D. d'emmerezi* Bez., *Ceratitis capitata* (Wied.), *C. catoirii* Guér., *C. rosa* Karsch and *Pardalaspis cyanescens* Bez. The two latter species entered the island recently. *P. cyanescens*, which attacks tomatoes, was found in 1958 attacking tomatoes in the north of the island and it has now spread considerably. It is probably indigenous to Madagascar where it attacks wild Solanaceae; it was recorded as a pest of tomatoes in Réunion Island in 1951.

Only two local parasites of fruit flies are known: *Eucoila* sp. on *C. capitata* and *Opius insignipennis* Granger on *C. catoirii*. They are scarce and exert little natural control. Introductions of parasites from Hawaii and other countries have been in progress since 1957; over fifteen species have been released and two, *Syntomosphyrum indicum* Silv. and *Opius oophilus* Fullaway, have been recovered.

Insecticidal methods of control are considerably handicapped by the infrequency of orchards, the greater number of the fruit trees on the island being scattered in small private gardens, so that systematic spraying is generally impossible. *P. cyanescens*, attacking tomatoes, is more amenable to insecticidal control since the locally favoured dwarf variety of tomato is mostly cultivated as a field crop. Dipterex sprays have proved efficacious and good control is possible.

Pests of Coconut

The Rhinoceros beetle, *Oryctes rhinoceros* (L.), is a major pest of coconut plantations in the island of Diego Garcia, a dependency of Mauritius. Consignments of the Histerid predator, *Hololepta quadridentata* (F.), were recently sent to the island and an effort is being made to obtain the Carabid, *Scarites madagascariensis*, Dej. from Madagascar for trial. The wasp *Scolia ruficornis* F., which had been obtained from Zanzibar and sent to Diego Garcia in 1951, was found in 1956 to be firmly established there but it does not appear to have reduced the economic importance of the beetle to any great extent. The application of BHC mixed with fine sand has given good protection to young trees when placed in the leaf axils.

The Rhinoceros beetle does not exist in Mauritius but a mite, *Raoilla indica* Hirst, causes much damage to young trees. Experiments with Metasystox, Rogor 40, Tedion V–18 have given good results.

The Banana Weevil

Two Histerid beetles, *Hololepta quadridentata* and *Plaesius javanus* Erichs were introduced from Trinidad in 1959 against the banana weevil, *Cosmopolites sordidus* (Germ.). Neither has yet been recovered.

Weed control

The successful control of black sage *Cordia macrostachya* (Jacq.), R. & S., in Mauritius by the introduction of two insects, *Schematiza cordiae* Barber and *Eurytoma* sp., was described in the report of the previous conference. No further work on the subject was done during the period under review although an account of the biology and bionomics of the latter insect, as well as notes upon the present ecological status of the weed, have been published recently (Williams, 1960). It is, however, of interest to record here that the suppression of the weed by the two insects has now been maintained for nearly ten years and it may be concluded that recrudescence of the weed will occur only in the unlikely event of some new factor disturbing the equilibrium of the present plant-insect biotic system. The control of *Cordia macrostachya* in Mauritius has been so eminently successful and its *modus operandi* so clear that it may be considered a classic example of weed control by means of insects.

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NEW ZEALAND

REVIEW OF WORK IN ECONOMIC ENTOMOLOGY

In New Zealand the Institutions that have contributed material for this review are:—

(1) Massey Agricultural College, Palmerston North.
(2) Canterbury Agricultural College, Lincoln.
(3) Department of Agriculture:
    (a) Wallaceville Animal Research Station.
    (b) Farm Advisory Division.
    (c) Horticultural Division.
(4) New Zealand Forest Service:
    Forest Research Institute, Whakarewarewa, Rotorua.
(5) Department of Scientific and Industrial Research:
    (a) Plant Diseases Division, Auckland.
    (b) Entomology Division, Nelson.

The main change in entomological organization in New Zealand since 1954 concerns the Entomology Division, D.S.I.R., which at present has a staff of twenty-nine officers, made up of twenty-five professional and technical staff and four clerical officers. This is the largest entomological organization in the country. It was previously known as the Entomological Research Station and under this title it was a joint responsibility of D.S.I.R. and the Cawthron Institute. Since 1956, however, it has been known as Entomology Division, D.S.I.R., and all entomology previously handled by Cawthron has come over to it. The Institute now has no entomological staff.

The work that has been carried out on the very wide range of applied problems is summarised below.

PASTURES AND FIELD CROPS

Grass Grub—*Costelytra zealandica* F. B. White

This Melolonthid continues to be the pest of major economic importance in New Zealand. The losses in production caused by it are variously estimated from £15,000,000 to £30,000,000 annually. Though recommendations for control were worked out prior to 1950, work has continued year by year on side issues, such as toxicity to plants, to stock and to humans, and also to overcome problems in application of chemicals.

By the end of 1954, over 75,000 acres had been treated with DDT at a maximum rate of 2 lb. pp′ DDT per acre (67 tons of DDT) and by 1957–60 it was estimated that 525–600 tons of 100 per cent. pp′ DDT were being used annually in this country to control this insect. The emphasis is that farmers should use DDT in a definite rotation in the same way that they use fertilizers. The DDT is commonly applied in a " dry mix " superphosphate mixture or in a " wet mix " superphosphate mixture. As the name suggests, in the " dry mix " the superphosphate and finely ground DDT are mixed mechanically in the dry. In the " wet mix " the DDT is incorporated with the superphosphate during the course of manufacture of the latter. It is necessarily considerably coarser in particle size of DDT than is the " dry mix." The " dry mix," because of this fine DDT particle, is more suitable than the " wet mix " for quick grub killing in pastures, but the " wet mix " is more suitable for aeroplane application and is also quite satisfactory for " insurance " treatment of pasture to prevent grub infestation from year to year. In the past there has been considerable dissatisfaction with the evenness of mixing of these DDT-superphosphate products but now the standard is generally good.

A dosage of 2 lb. DDT per acre, if correctly applied, continues to give protection in grassland over a period of three seasons. Investigational trials are now being proposed on soil type differences correlated with effectiveness of DDT.

Though there are other materials such as aldrin and dieldrin which kill more grubs than does the same dosage of DDT in the same time, emphasis is placed on the use of DDT because it is effective and has a lower mammalian toxicity.

In plant toxicity tests it was found that DDT at recommended dosages was safe to use with any pasture or crop plant, but that BHC or lindane caused plant injury if a rate of 0·5 lb. per acre was used in seven-inch drills or as seed dressings. Other tests showed that if recommendations for application were carried out properly, 2 lb. DDT or lindane per acre could be used safely on pastures without uptake by grazing stock or by the plant itself.

It has been shown that main flights of the beetle occurred at temperatures above 49° F., in absence of rain and in winds of less than 10 m.p.h., but that emergence from the ground, or feeding, occurred each night. Over the whole flight period, not more than 5 per cent. of beetles captured in " white " light traps were females, though single night collections sometimes had as high as 25 per cent. of females. More beetles were collected at strong than weak lights but there was no increase in the female to male ratio. Normally this ratio shows a slight dominance of female numbers. There is some evidence to suggest that the widespread use of DDT on grazing land may cause large deviations in this ratio from normal; in such cases, female predominance has been very marked. In three small-scale tests, DDT treatment of third-instar larvae in the soil resulted in very few male beetles emerging but the female population was normal. Dissection of female beetles over the whole flight season in female-dominant areas showed that over 80 per cent. of such females were unmated at the ends of flights.

The use of parasites of the sub-family Thynninae from Australia led to the initial establishment of one species for the first three years, but no recovery has been made since then. Control by bacterial spore dust and by the eelworm *Neoaplectana glaseri* have been attempted in a preliminary way. The success of the DDT applications has been so great that biological methods have rather fallen into abeyance.

Subterranean Grass Caterpillar—*Oxycanus* spp.

These Hepialids belong to the genus *Oxycanus*. There are three species that cause major damage to pastures, and to a lesser extent to crops throughout New Zealand. They usually appear in the same areas that are infested by grass grub and it is not always easy to separate the amount of damage done by the two insects.

This pest is controlled by the same measures as are used against grass grubs.

Armyworms—*Persectania aversa* (Wlk.) and *Pseudaletia separata* (Wlk.)

These two species have become much more important in New Zealand in the last ten years. *P. aversa* is a native species whilst *Ps. separata* is cosmopolitan. Larval sampling and rearing shows *Ps. separata* to be the important species in the North Island. In the South Island, the position is as follows—in Canterbury, *P. aversa* is the dominant species; in Nelson and Marlborough, although *Ps. separata* is dominant, *P. aversa* has also been reared from these areas. Life cycles of both armyworms have been studied under field conditions. In Nelson, three generations of both have been reared in one season.

Parasites attacking armyworm are *Lissopimpla excelsa* Costa; *Ichneumon promissorius* Erich. (pupal parasites); *Apanteles ruficrus* Hal. and *Euplectrus* sp. near *noctuidiphagus* Yats. (larval parasites).

Sprays and dust of dieldrin, 0·5 lb. per acre or DDT 0·5–1 lb. per acre give good control. Current experiments are being conducted on the use of lower rates of these and other chemicals, particularly in dust form, such as mixtures with superphosphate.

Stem Weevil—*Hyperodes bonariensis* Kuschell

This insect, which was hitherto called the Argentine stem weevil *Hyperodes griseus* Hust., has been shown recently to be *H. bonariensis* Kuschell. It is a serious pest in the vegetative growth of the four varieties of ryegrass (*Lolium*) grown in New Zealand, the larvae feeding in the tillers of the plants. Work over the past five years has shown that heavy losses in ryegrass can be caused by this weevil. It is also a pest of timothy and is responsible for straw damage in cereal crops.

Control of *H. bonariensis* has not been worked out thoroughly but preliminary work showed that a dosage of 2·5 lb. pp′ DDT per acre was better than the same amount of lindane, and 2·5 lb. dieldrin per acre gave better results than did that amount of DDT. All materials were applied as sprays. Treatment must be applied just prior to oviposition as control measures were impossible after eggs were laid. There are usually two, but occasionally three generations per year. Emergence of these generations is about two weeks earlier in the North than in the South Island.

Black Beetle—*Heteronychus sanctae-helenae* Blanch.

This insect has become an important pest of pastures, but is at present confined to coastal areas in the northern part of the North Island. Outbreaks of epidemic proportions have so far been sporadic. The beetle, which has one generation per annum, overwinters as an adult. Both larvae and adults cause pasture damage, showing a preference for *Paspalum dilatatum* Poir. Black beetle is usually more abundant in soils which are either light and friable or of a peaty nature.

Insecticide trials indicate that satisfactory control of *H. sanctae-helenae* in pasture can be secured with dieldrin-superphosphate mixtures at dosages as low as 4 oz. toxicant per acre.

White-Fringed Beetle—*Graphognathus leucoloma* (Boh.)

This beetle is becoming increasingly important in the fields of agriculture, horticulture and silviculture in the North Island. Investigation of the biology of *G. leucoloma* under New Zealand conditions has been commenced.

Field Cricket—*Acheta commodus* (Wlk.)

The cricket is restricted to the northern part of the North Island. It causes heavy damage to pasture where conditions, such as severe cracking of the ground in summer, are suitable for it. DDT and dieldrin are effective on crickets, especially the latter, which is effective at 0·5 lb. per acre. Current experiments are aimed at reducing this dosage.

Cabbage Aphid—*Brevicoryne brassicae* (L.)

This insect is a serious pest of crucifer, especially rape and swedes grown both for seeding and grazing purposes. It can be controlled effectively by the use of Metasystox at 16 fl. oz. per acre in not less than 10 gal. water per acre (by aeroplane). Against winged Aphids, however, treatment would have to be applied every fortnight as Metasystox did not prevent re-infestation and breeding from the sixth day after the initial spraying. Emphasis is placed on control of apterous forms from May onwards as this keeps crops free till the end of October when alates begin to re-infest crops.

This Aphid is also a vector of serious virus diseases in crucifers and in order to provide a background of information that will help in its general control, a comprehensive study of the ecology of the cabbage aphid in Canterbury Province is being undertaken. This work is now in its second season and the results of the first season's work have already thrown some light on aphid multiplication and dispersal in the field. Results of aphid trapping at three sites are being correlated with studies of static populations and with climate conditions.

Although the Braconid, *Diaeretus rapae* (Curt.), parasitises a considerable percentage of *B. brassicae* in the North Island, its effectiveness is limited by hyperparasitism.

Clover Case Bearers—*Coleophora* spp.

There are two species damaging white clover grown for seed, *viz.*, *C. spissicornis* (Haw.) and *C. ?alcyonipennella* (Koll.) and these have become limiting factors in the production of white clover seed in New Zealand.

Work carried out over several years has produced an hypothesis (which is necessitated by the occurrence of a two year larval hibernation in one and possibly both species) relating the imperfectly known biology to infestation and damage to clover seed in the field. Following the screening of insecticides for toxicity to honey bees by the Department of Agriculture, toxaphene and strobane have been used in preliminary trials applied to white clover crops in flower. Reduction in seed damage and increases in yield indicate that further trials with these materials are warranted.

Further work on biological control is being pursued. Searching for suitable parasites in Europe by the Commonwealth Institute of Biological Control is continuing but so far no very promising parasite has been located.

Pollination of Red Clover for Seed

As part of a general investigation on entomological factors affecting pollination of red clover and lucerne in New Zealand, a survey has been made of the bumble bee species present and their distribution in the South Island of New Zealand. There are no significant native pollinating insects for these crops and although hive bees were present and widespread in the country from 1839 until 1885, when bumble bees were first successfully introduced, no commercially profitable seed sets were obtained until the latter date. The inference then is that bumble bees are the principal pollinators of this crop. A further introduction of bumble bees was made in 1906. In neither case was there a record made of species introduced.

Several subsequent investigations produced conflicting reports on the species present. This present survey was undertaken in an endeavour to clarify the position and to provide other basic data on the ecology of the species of bumble bees present. The survey is now complete, some 380 localities have been sampled, some of these several times and most areas have been visited in the spring and autumn. Four species are shown to be present, *Bombus terrestris* (L.), *B. ruderatus* (F.), *B. subterraneus* (L.) subsp. *latreillellus* (Kirby), *B. hortorum* (L.)

B. terrestris and *B. ruderatus* are present throughout the island, while *B. subterraneus* subsp. *latreillellus* and *B. hortorum* appear to be confined to the eastern side of the main divide south of Amberley in North Canterbury.

Information on colonial cycles obtained shows a response to the milder climate of New Zealand by *B. terrestris* in that nests sometimes survive the winter. No evidence exists of a similar response in the other species.

White Butterfly—*Pieris rapae* (L.)

In the North Island virus disease causes heavy mortality of white butterfly during the latter part of the season when parasitism by *Pteromalus puparum* (L.) also reaches a high level. The larval parasite, *Apanteles glomeratus* (L.), does not exercise control. Cruciferous field crops are no longer, in general, affected to a major degree by white butterfly.

In Canterbury, in the South Island, the butterfly appears to be in a state of equilibrium with the two parasites *A. glomeratus* and *P. puparum* and a granulosis virus. *A. glomeratus* is the more important parasite early in the season and the virus in later stages of infestation. Preliminary results with virus spray suspensions have given good results. The parasite and virus complex makes it unnecessary to use insecticides for field crop protection.

Diamond-back Moth—*Plutella maculipennis* (Curt.)

In the North Island this pest of crucifers is effectively controlled by *Angitia cerophaga* (Grav.) and *Diadromus collaris* (Grav.), particularly by the latter. Both of these parasites have been introduced from overseas. In the autumn there is also a fungus disease that assumes importance.

In the South Island diamond-back moth continues to be a serious pest of turnip crops. It is controlled effectively with DDT at the rate of 0·5 lb. pp′ per acre as a spray using at least 15 gal. water, or 1 lb. pp′ DDT per acre as a dust. The moth is usually controlled in the field from mid-March onwards by a complex of bacterial and fungal parasites and virus.

Potato Tuber Moth—*Gnorimoschema operculella* (Zell.)

This is a pest of potatoes wherever they are grown especially in the North Island. Although spraying is carried out in some districts, the effectiveness of this method of control under our conditions is not adequately known. An effective parasite would be a great boon.

Cocksfoot Seed Thrips—*Chirothrips pallidicornis* Pries.

Eight species of thrips have been found infesting cocksfoot seed crops but *C. pallidicornis* is by far the most predominant species. In many districts it has been abundant in cocksfoot for several years and in such areas the seed loss may be close to 50 per cent. Eggs are laid after anthesis in the ovary itself and nymphs do not leave that seed until they transform to adults. Control measures with dieldrin-Metasystox gave 100 per cent. control of adults, but did not prevent seed loss if eggs had been laid, as Metasystox even at 32 fl. oz. per acre applied in two applications of 16 fl. oz. per acre in a period of eight days had no effect on nymphal stages.

Springtails

In the South Island the springtails *Bourletiella hortensis* (Fitch), *B. arvalis* (Fitch), and *B. arvalis* subsp. *dorsobsoura* Salmon. can be serious pests of young cruciferous crops, particularly in the cotyledon stage. Control is secured by applying 0.5 lb. lindane per acre as a spray in ten to fifteen gal. water per acre, depending on the density of the leafage.

The Plant Bug—*Nysius huttoni* White

This is a serious pest of cruciferous crops, wheat and sometimes grasses. It may be controlled by 1–2 lb. pp′ DDT per acre in fertiliser or at 0·5 lb. per acre as a spray, the volume of water increasing with density of crop.

Cutworm—*Agrotis ypsilon* (Hfn.)

This insect is a consistent pest of many crops and is particularly troublesome in clover seed crops. Control is secured by using lindane at 1 lb. per acre, employing at least 20 gal. water per acre.

Wireworms

Two undetermined species of wireworms (Elateridae) occur frequently in cereal and cruciferous crops and occasionally in potatoes. Laboratory tests showed the following order of effectiveness against them:—lindane, dieldrin, DDT and aldrin, but exact field dosages have not yet been worked out.

Carrot Rust Fly—*Psila rosae* (F.)

The application of lindane to carrot seed has given successful field control of this pest.

HORTICULTURE

Green Vegetable Bug—*Nezara viridula* (L.)

Distribution of the egg parasite *Microphanurus basalis* (Woll.) was discontinued in 1959 as results appeared to be somewhat unsatisfactory. Although temporary good control may be exercised by this parasite in local areas, permanent and widespread control is not achieved. The prospects of further parasites are being investigated.

Scale Insects on Fruit

A survey of scale insects on apples showed the following species on wood and fruit, *Quadraspidiotus perniciosus* (Comst.); *Q. ostreaeformis* (Curt.); *Lepidosaphes ulmi* (L.); *Parlatoria pittospori* Mask.; *P. virescens* Mask.; *Lindingaspis rossi* (Mask.); and *Hemiberlesia rapax* (Comst.). All but the last and the second to last species above were capable of producing red markings on fruit.

San José scale, *Q. perniciosus*, has become more prevalent in orchards. This may be the result of the change from red oil to superior type oils or the replacement of both oil and lime-sulphur from the spray programme, but is more likely to be the result of biological changes. In addition to dormant spray application it is necessary to employ summer control measures. Sevin, the new carbamate insecticide, has shown great promise against San José when used on apples in the summer.

The life-history of the San José scale has been studied in the Auckland district; three generations occur, with considerable overlapping, and a few crawlers are released even in the winter. By means of sticky traps, it was shown that crawlers are readily spread by wind in infested orchards.

The parasite *Prospaltella perniciosi* Tow. has been introduced against San José scale during the 1959–60 summer and there is evidence to indicate that the first generation adults have emerged at liberation sites. Further parasite species will shortly be tried and all species established will be tested against other scale species.

Parlatoria pittospori has become increasingly troublesome in apple orchards in some districts. Observations to date show that it is periodically blown on to apple fruits in the orchard from surrounding shelter belts of pines, *Pinus radiata* Don., on which the species breeds freely. Indications are that elimination of the scale on such shelter belts will solve the problem.

Red Spider Mites on Apples

A survey of the species infesting apples showed that the European red spider mite *Panonychus ulmi* (Koch.) was the most widespread and damaging species though substantial summer infestations of *Tetranychus telarius* (L.) were found in a few districts. *Bryobia praetiosa* Koch, though widespread, was not generally a serious pest.

The natural enemies of red spider mites in New Zealand are at present being investigated by Dr. E. Collyer of East Malling, England.

As far as chemical control of *P. ulmi* is concerned, control measures have changed from oils to ovicides, to residual or systematic organic phosphorus compounds but there is evidence that this trend may be reversed because of the development in the field of mite populations very resistant to organo-phosphate materials.

Mealybug—*Pseudococcus* spp.

Pseudococcus spp. continue to be troublesome on pears in some districts particularly since DDT is no longer effective. Again, Sevin is showing promise.

Apple Leafhopper—*Edwardsiana australis* Frogg.

This insect is not now controlled by DDT but malathion gives good control.

Chrysanthemum Gall Midge—*Diarthronomyia chrysanthemi* Ahl.

First found in Auckland in 1953, by 1957 this species had spread through most of the North Island. It is a serious pest since chrysanthemums are grown almost entirely outdoors in this country. It completes its life history in four weeks in the insectary. Regular applications of parathion controlled existing infestations but schradan, BHC, DDT and nicotine sulphate were ineffective. There is a wide range of varietal resistance to gall midge attack.

Citrus Leafrollers

Surveys between 1955–57 showed that *Ctenopseustis obliquana* (Wlk.) was by far the most abundant species but the following species were also found on citrus: *Epalxiphora axenana* Meyr., *Austrotortrix postvittana* (Wlk.), *Tortrix excessana* Wlk. and *Cnephasia jactatana* (Wlk.). In one area where DDT was extensively used, *A. postvittana* was the dominant species—no doubt as a result of the known resistance of this species to DDT.

Plant Galls

Studies of New Zealand plant galls and their causal insects and mites have continued. A catalogue of New Zealand plant galls has been prepared and is at present in the press.

Apple leaf-curling Midge—*Dasyneura mali* (Kieff.)

This insect, first reported in New Zealand in 1950, is now an established pest in many North Island orchard areas. The egg parasite *Prosactogaster demades* (Wlk.) originally introduced to control *Dasyneura pyri* (Bouché) was observed attacking *D. mali* during the 1954–55 season. As far as can be ascertained there are no records of this parasite attacking *D. mali* in England or the Continent where both the midge and parasite are present. There are normally five generations of *D. mali* between early October and late

April, the severest infestations occurring during the second and third generations when trees are making maximum growth. There is no marked varietal susceptibility, the degree of infestation being determined by the quantity of terminal growth. The effectiveness of *P. demades* as a parasite is limited by the failure to check the second generation of *D. mali*. Use of chemicals against the second generation complements biological control.

Fore-warning of Codling Moth and Leafroller Populations to Orchardists

Studies are being made of the levels of adult populations of codling moth, *Cydia pomonella* (L.), and leafroller, *Austrotortrix postvittana* (Wlk.), in apple orchards in Nelson. These are being studied by recording catches in mercury-vapour light traps. Growers are warned by notices in the local newspaper and on the radio when populations reach danger points so that extra spraying precautions can be taken at these times. Attempts are being made to correlate moth counts with the result of spraying experiments. Meteorological data is recorded in the orchards where the light traps operate and efforts are being made to relate these to the occurrence of moth populations. This work has been carried on for several seasons and is now being worked up for publication.

STORED PRODUCTS

Mites and the beetles *Ptinus tectus* Boield. and *Oryzaephilus surinamensis* (L.) cause trouble in grain stores in Canterbury wherever grain is stored for two years or more. The most effective treatment was a micronised dust composed of five parts DDT and one part lindane, used as a routine treatment on the floors of stores and the outsides of bagged grain.

In certain districts the Angoumois grain moth, *Sitotroga cerealella* (Ol.), causes damage in storage bins of maize cobs. Work is proceeding on the control of this pest.

PESTS OF FOREST TREES AND PRODUCTS

Work is concentrated upon insects of the main exotic trees *Pinus radiata* Don and Douglas fir (*Pseudotsuga taxifolia* Brit.). The most important insects are *Sirex noctilio* F., *Hylastes ater* (Payk.) and native defoliators such as the Geometrid, *Selidosema suavis* (Butl.). Work is also conducted on native forests, particularly various species of *Nothofagus*. Many insects are dealt with, the most important of which are a Buprestid, *Platypus* spp. and defoliators.

Biological control of *S. noctilio* is being conducted with the importation of *Ibalia leucospoides* (Hochenw.) and of the Douglas fir seed chalcid, *Megastigmus spermotrophus* Wachtl., by means of *Amblymerus apicalis* Thomson.

A biological survey modelled on that in Canada is conducted giving a coverage of New Zealand forested areas with ten observers stationed throughout the country. They send routine collections and reports to headquarters.

Chemical control of white grubs (*Costelytra*) and other insects in forestry nurseries, and of epidemic outbreaks of defoliators, is also dealt with.

Oak Leaf Miner—*Lithocolletis messaniella* Zell.

This pest of European origin was first recorded in New Zealand in February, 1951. Since then it has spread rapidly and has done severe damage to oaks, at times completely destroying the leaf tissue of deciduous species and causing complete defoliation of some evergreen species during winter. Other plants infested have been beeches, birch, hornbeam, ironwood, liquidamber, pecan, feijoa and apple. In addition, when populations were at peak levels, a wide range of secondary food plants including indigenous forest trees were attacked and in a number of cases the pest was able to complete its life cycle on these trees.

The internal larval parasite, *Apanteles circumscriptus* Nees, was introduced and successfully established in 1957, resulting in a considerable drop in population of the pest. During the summer of 1957–58 the multiple larval parasite, *Enaysma splendens* de L., was introduced and establishment proved by late 1958. This parasite is now in a stable state of establishment in the Nelson district where populations of the pest have been reduced by 90 per cent.

or more of the peak level. Liberations are now being made in selected areas in both North and South Islands.

In Nelson, where approximate stability has been reached, the pest population is no longer obvious and damage to oaks is negligible.

Coccids on Rata and Kamahi

During 1955–56 a survey was made in an attempt to elucidate the role of Coccids in mortality of rata, *Metrosideros umbellata* Cav. and *M. robusta* A. Cunn. and kamahi, *Weinmannia racemosa* L., in protection forests of Westland and sub-montane forests of the North Island. Although a number of new Coccid species were found, Coccids were not considered primary factors in rata mortality nor were they important in kamahi mortality.

Pests of Forest Products

Boron compounds are now extensively used for the treatment of building timbers against the borers *Anobium punctatum* (Deg.), *Ambeodontus tristis* (F.) and *Lyctus* spp. Approximately 100,000,000 board feet per year are being impregnated by both diffusion and pressure impregnation.

Plywood and particle board are being protected from borer attack by the addition of dieldrin to the glue at the rate of 0·015 lb. per cu. ft. of particle board or of 0·3 per cent. of prepared glue weight for plywood.

For control of *Anobium punctatum* infestations in existing buildings diesel oil is now widely used in New Zealand and is giving excellent results. Both the staining and oiliness are disadvantages which prevent diesel oil being used in some situations. A long term test of the effectiveness of diesel oil and fractions has shown that these disadvantages cannot readily be reduced by moderate refining procedures. The light fractions give good initial control but are not long lasting, while the heavy fractions give poor initial control but are very long lasting and readily prevent reinfestation. Hence the effectiveness of diesel oil appears to derive from a blend of separate effects.

Ten years' results from long term trials on the effectiveness of various materials for prevention of infestation by *Anobium* are now available. Materials under test include diesel oil and fractions, pentachlorphenol, copper naphthenate and the four chlorinated insecticides DDT, DDD, lindane and dieldrin, each at a range of concentrations. The light oil fractions and pentachlorphenol have failed completely; heavy oil fractions and copper naphthenate have failed except at the highest concentrations; none of the chlorinated insecticides have failed except DDT and DDD at 0·2 per cent. These trials are continuing.

A recent test has shown that insecticidal smokes are not effective means of controlling *Anobium* infestations; beetles that have already emerged are controlled but subsequent emergence is hardly affected. Hence, the extensive use of these materials in New Zealand should be discontinued.

The termite, *Coptotermes acinaciformis* (Frogg.), and other Australian species of the genus have been established in some cities of the North Island, particularly in Auckland and New Plymouth. A campaign of inspection and arsenic dust treatment operated by a group of Borough and City Councils working together has brought about the almost complete extermination of these termites from these cities.

Work is being carried out on *Ernobius mollis* (L.) which affects pine timber with bark attached, and also on *Hylotrupes bajulus* (L.).

MAN AND STOCK

The first Argasid tick (*Ornithodorus capensis* Neumann) was recorded from New Zealand. It is unlikely to be more than an occasional parasite of man or domestic animals.

A survey is in progress to determine the distribution and breeding places of the Simuliidae, two of which are potential vectors of virus diseases of man and stock.

Attempts to establish the histerid predator *Pachylister chinensis* (Quens.) and the coprid food competitor *Copris incertus* Say. against houseflies have failed, although a colony of the latter maintained in an open-air insectary has permitted the making of a valuable study of the biology of this insect. Further avenues of control of muscid flies are being investigated.

Substantial swarms of Chironomid midges were a nuisance to Auckland residents last summer. It was found that the reclamation of some 1,500 acres of harbour mudflats for conversion to oxidation ponds had produced ideal conditions for massive breeding of Chironomid midges. The main species concerned is *Chironomus zealandicus* Hudson and the life-history and habits of this species are under investigation. Drainage authorities have obtained adequate control by aerial application of dieldrin or DDT.

Work has been carried out on the ecology and control of the sheep ked, *Melophagus ovinus* (L.), and *Damalinia ovis* (L.) on sheep, with special reference to the surface application of dieldrin, aldrin and diazinon in the form of dusts or low-volume sprays, and with orthodox plunge dipping methods.

A dieldrin-resistant strain of *Lucilia sericata* (Mg.) has been found on fly-struck sheep in Marlborough and is at present under study. Two parasitic mites, *Ornithonyssus sylviarum* (C. & F.) and *Psorergates ovis* Womersley, were reported for the first time from New Zealand.

A quick method of applying insecticidal dusts to small laboratory animals to control external parasites has been devised.

Unpublished work has been done on the toxicity of insecticides to higher mammals, particularly of dieldrin and aldrin in dogs and the residues of insecticides found in meat and dairy produce after the routine treatment of livestock or of the pasture on which they are grazing.

The sharp increase in the incidence of biting fly, *Stomoxys calcitrans* (L.) in the warmer dairying districts of the North Island, in recent years has been primarily caused by an increase in silage making and general abandonment of the habit of covering ensilage stacks. Because of its irritating effect on cows, the fly is responsible for a considerable loss in dairy production when present in large numbers. Uncovered ensilage stacks, open compost heaps and piles of grass mowings or any decaying vegetation are primary breeding sites. Experimental work is being conducted towards removing these breeding sites, and also to giving animals some relief by the use of sprayed repellents.

The poultry mite *Cnemidocoptes mutans* (Rob. & Lanq.) was controlled in commercial houses by application of 0·5 per cent. lindane in linseed oil to the legs and feet of infested poultry. There was no irritation caused by this treatment.

BIOLOGICAL CONTROL

Surveys are being initiated to obtain the following information:—

(i) The presence or absence, distribution and effectiveness of previously liberated parasites and predators.

(ii) The parasite, predator complex on any available insect species, native or introduced, particularly those of economic importance.

(iii) The parasite, predator complex present on pests listed for future biological control attempts.

To date the above survey is on a restricted basis in an attempt to develop methods of rearing, preservation and recording.

A dry spore preparation of *Bacillus thuringiensis* Berl. is being tested against a number of lepidopterous and other larvae.

A study has been made of the following important weed problems.

Manuka—*Leptospermum scoparium* Forst.

Manuka, a native New Zealand plant, often encroaches on to grassland and in such situations is considered a weed by New Zealand farmers. It has been killed out over thousands of acres of such land by an organism called “ manuka blight ” which arrived in New Zealand accidentally, not having been purposely introduced.

The causal organism of manuka blight is the Coccid *Eriococcus orariensis* Hoy. which has become established by means of natural dispersion and deliberate transfer in almost all large stands of *Leptospermum scoparium* Forst. in New Zealand. This insect has been studied to explain its role in killing manuka and to provide fundamental information which may be of use in future attempts at biological control of weeds. In a survey in that country it has been found that *E. orariensis* is the principal coccid species on *Leptospermum* in Australia.

The results of this investigation have been given in a series of three papers. The first dealing with the morphology of *E. orariensis* and the second with the complex of *Eriococcus* species associated with *Leptospermum* in Australia. The third paper, now in the course of publication, details the life-history and distribution of the Coccid in New Zealand, its effect on host plants and the occurrence of an insect parasitic fungus (*Myrangium thwaitessi* Petch.) attacking *E. orariensis*. This fungus has been responsible for a spectacular decline in the effectiveness of *E. orariensis* as a controlling agent for manuka in high rainfall areas.

Mexican Devil Weed—*Eupatorium adenophorum* Spreng.

This weed is gaining a hold in some areas in the Auckland province of the North Island. Following requests from the Department of Agriculture for the exploration of biological means of controlling this weed in 1958, the stem gall fly *Procecidochares utilis* Stone was introduced from Australia. The insect has been established at two liberation sites and appears to be spreading.

Ragwort—*Senecio jacobaea* L.

The seed fly, *Hylemyia seneciella* (Meade), was liberated in a selected area in 1937 and by 1954 the area infested was approximately ten square miles in which counts indicated that over 87 per cent. of all flowers had been infested. It was calculated, however, that in this area it would require 100 per cent. of seed to be destroyed, because if only 0·0018 per cent. of viable seed was left that would be sufficient to keep the number of ragwort plants the same from year to year, *i.e.* an average of 34 flowering plants per 100 square feet.

During 1958–59, a total of approximately 24,000 puparia of the introduced ragwort seed fly was collected and dispatched to Australia for use in a biological control project against ragwort.

PLANT RESISTANCE TO INSECTS AND INSECT PHYSIOLOGY

Extensive field, glasshouse and laboratory studies have been made of aphid-host relationships with special reference to the cabbage aphid, *Brevicoryne brassicae* (L.), on brassica field crops. Four swede varieties have been shown to have some measure of aphid resistance which, although an hereditary character, depends greatly upon the physiological condition of the host plant for its expression. Such features as leaf age and chemical composition and host/water status have been studied in relation to their effects on aphid multiplication and survival.

Excretion in the cabbage aphid, *B. brassicae* (L.), was found to be ammonotelic. Some effects of temperature on respiration and reproduction have also been investigated.

INSECT SURVEYS

Basic surveys of the insects associated with pastures in New Zealand commenced in the summer of 1957 and have continued since. Techniques for rapid sampling were devised and the results from a survey of more than 100 stations based on the various pasture types which occur throughout the North Island have been recorded in a series of ten papers. The first of these analyses the complex as a whole and compares the fauna of adjacent roadside cover. The subsequent papers are concerned with the species identity, distribution and possible economic importance.

Besides providing basic economic collections and a useful inventory of the insects associated with pastures—including the detection of previously unrecorded overseas species—the survey has highlighted the complexity of the pasture fauna. More than thirty genera of Hymenoptera are recorded for the first time from New Zealand. Data useful in determining research priorities has been obtained.

Surveys of insects associated with cruciferous crops, mangolds, lucerne, and maize crops in the North Island were carried out during the summer of 1959. The information obtained is being prepared for publication. This is the second stage of a D.S.I.R. project which envisages the periodic survey of all non-forestry agricultural crops.

No successful results have been demonstrated in the investigation of control of virus spread in the field by means of insect vector control.

In testing the possibilities of insecticidal seed treatments, no advantage has been found by using residual insecticides on cereal seed. No useful field application has yet been found for systemic insecticidal seed treatments.

Insecticide application has received some attention, particularly as it applied to field scale treatment. Aerial application gave the poorest results and tests showed that in winds of less than 2 m.p.h. and an altitude of 50 feet the loss off the seven acre target was in the vicinity of 50 per cent. Swathe widths did not increase with altitude and were always less than the wing span of 'planes.

QUARANTINE

New Zealand has revised its Plant Quarantine Regulations to meet modern needs and is installing up-to-date plants for fumigation with methyl bromide, at ordinary and atmospheric pressures. Two large plants at Wellington and Auckland have been completed and smaller ones are situated at New Plymouth, Christchurch, Timaru, Dunedin and Invercargill. A new plant is about to be erected in Christchurch.

Interceptions of Arthropods

Under the Plant Quarantine Regulations 1957/1960, 446 interceptions were recorded at ports and international airports in New Zealand for the period 1954–59—Coleoptera 157, Hemiptera 87, Lepidoptera 48, Hymenoptera 40, Diptera 36, Orthoptera 27, Arachnida 26, and Miscellaneous 25.

Of these, 186 came by sea, 160 by air and 99 by parcel post.

Coleoptera

Sixty-one (approx. 40 per cent.) of the 157 interceptions were associated with stored products, most being of economic significance. The commonest were the tobacco beetle, *Lasioderma serricorne* (F.); the drugstore beetle, *Stegobium paniceum* (L.); the saw tooth grain beetle, *Oryzaephilus surinamensis* (L.); the merchant grain beetle, *O. mercator* (Fauv.); the rice weevil, *Sitophilus oryzae* (L.); the flour beetle, *Tribolium castaneum* (Herbst.); the red-legged ham beetle, *Necrobia rufipes* (Deg.) and members of the families Dermestidae and Bruchidae.

The sweet-potato weevil *Euscepes postfasciatus* (Fairm.) was recorded on four occasions, all associated with kumaras.

A number of wood-boring insects were encountered in packing cases, wooden crates and bamboo articles. These included *Dinoderus minutus* (F.) and *Sinoxylon conigerum* Gerst. in bamboo containers from India and Ceylon; *Callidium violaceum* (L.) in timber from Sweden, and a live adult of *Monochamus titillator* (F.) in general cargo from North America.

Hemiptera

The greatest bulk of the Hemiptera consisted of scale insects (Coccidae), 56 of the 87 specimens belonging to this group. The most commonly occurring species were *Aonidiella aurantii* (Mask.), *Chrysomphalus ficus* Ashm. and *Lepidosaphes beckii* (Newm.), 12, 8 and 6 interceptions respectively. All were on citrus fruit. There was one instance of yellow scale, *Aonidiella citrina* (Coq.), on oranges from U.S.A.

Mealybugs, *Pseudococcus* spp. were encountered on four occasions.

The tulip bulb aphid *Anuraphis tulipae* (Boy.) was intercepted on five occasions—mainly on iris tubers from U.S.A. and United Kingdom.

Lepidoptera

Sixteen interceptions of the family Noctuidae were encountered. The most notable of these was *Prodenia litura* (F.)

Egg rafts of what is probably this moth were found on the outside of aircraft on four occasions, in each instance the aircraft being from Fiji. An adult was also taken in aircraft crates from the U.S.A. This species temporarily occurred in the tobacco fields at Motueka in February 1955, but was eradicated.

Nine interceptions of the family Phycitidae were recorded, practically all of these being pests of stored products such as *Plodia interpunctella* (Hb.) or *Ephestia* spp.

Two instances occurred of what is thought to be the larvae of the false codling moth, *Argyroploce leucotreta* Meyr., killed by cold storage. These were in oranges from South Africa.

The bean pod borer *Maruca testulalis* (Geyer) was encountered twice in beans from Fiji and there was one instance of the occurrence of the larvae of *Pyrausta nubilalis* (Hb.) in broom millet from Italy.

Hymenoptera

Three-quarters of this group were ants (Formicidae). Probably the most notable was that of *Iridomyrmex darwiniensis* (Forel) which was found in a timber yard at Penrose, Auckland. This is believed to have been exterminated. The commonest interceptions were those of *Monomorium pharaonis* (L.) and *Pheidole* spp. mainly *P. megacephala* (F.). Other ants of some economic importance were *Iridomyrmex* spp. and *Camponotus* spp. and *Paratrechina longicornis* (Latr.). Most ants were received from Australia.

Diptera

Ten interceptions occurred of the family Culicidae. Practically all of these were in aircraft from Australia and Fiji. Eight specimens belonged to the genus *Culex* and the other two to *Aëdes*. Specific identifications were difficult because of the damaged nature of most of the specimens.

Larvae of fruit fly (Trypetidae) have been found once in mangoes from the Philippine Islands and twice in oranges from Cyprus. The chrysanthemum gall midge, *Diarthronomyia chrysanthemi* Ahl., was also intercepted.

Acarina

The bulb mite *Rhizoglyphus echinopus* (F. & R.) was often encountered on bulbs from Holland.

NORTHERN NIGERIA

1. REVIEW OF WORK IN AGRICULTURAL ENTOMOLOGY

By M. A. Choyce

Ministry of Agriculture

Organisation and Staff

A comprehensive agricultural research scheme, with headquarters at the Regional Research Station, Ministry of Agriculture, Samaru, Zaria, was initiated in 1954–55. This substantially enlarged the existing research services of the Ministry, with the aim of providing a sound basis for a progressive improvement in the agricultural industry of the Region. Within the scheme provision was made for five entomologists, and these posts were all filled by August, 1958.

Apart from advisory work, the principal research work now in progress, much of it in co-operation with other specialists, is as follows:—

(a) Pests of cotton—M. A. Choyce and W. Reed (on secondment from the Empire Cotton Growing Corporation).

(b) Pests of citrus—the aphid vector of groundnut rosette disease in the northern provinces—R. H. Booker.

(c) The aphid vector of groundnut rosette disease in the riverain provinces; cotton pests at Mokwa (at the sub-Research Station, Mokwa, Niger Province); yam beetles (in co-operation with Federal Research)—J. A'Brook.

(d) Pests of grain stores by peasant farmers—P. H. Giles.

During the period under review Mr. K. M. Harris, Entomologist, Federal Agricultural Research (investigating cereal stem borers and sorghum midge), and Mr. W. A. Sands, Colonial Termite Research Unit, worked at the Regional Research Station.

The information in this review has been obtained from the Annual Reports of the Ministry of Agriculture, Progress Reports from Experiment Stations (Northern Nigeria) of the Empire Cotton Growing Corporation, and from unpublished observations of the officers concerned.

Cotton Pests

Investigations on cotton in Northern Nigeria during the past few years have attempted to define the conditions under which the crop should be grown to give the maximum yield. The use of insecticides has proved essential to enable the full potential of the crop to be realised; on the other hand, insecticide application on cotton without a high yield potential has been of little value. Sowing date is of primary importance; the highest yields have almost invariably been obtained from cotton sown during June. At Samaru, agronomic treatments, including early land preparation, cross-tying of ridges, mulching and subsoiling, have been effective in improving the seasonal crop-soil water relationship. Except on very fertile soil, significant yield increases have been obtained following the application of sulphate of ammonia and superphosphate within two weeks of sowing.

Early sown cotton grown under favourable conditions sets a heavy crop of bolls during September; at this period there is usually a migration of stainers, *Dysdercus superstitiosus* (F.), into the cotton. These induce a high rate of shedding of young buds and bolls, and cause extensive internal boll rots in older non-shedding bolls. The stainers breed within the crop until harvest. Bollworms also enter the crop early in the season, but become most numerous during October–December. The red bollworm, *Diparopsis watersi* (Roths.) is the most important; other bollworms include *Pectinophora gossypiella* (Saund.), *Earias* spp., *Heliothis armigera* (Hb.), and *Argyroploce leucotreta* Meyr. The Mirids, *Campylomma* sp. and *Lygus vosseleri* Popp., can build up large populations during early October.

Complete protection from pests would, therefore, require a series of insecticide treatments from soon after flowering to harvest. In practice, substantial yield increases have been obtained by a restricted number of sprays during September and early October, aimed at control of the initial invasion of stainers. These early sprays also prevent damage by Mirids and reduce the early bollworm attack, besides giving protection against various minor pests, such as the leaf roller, *Sylepta derogata* (F.). Most of the yield from sprayed cotton is given by the early pickings, and this early maturity reduces the period during which bollworms can increase within the crop. A DDT/BHC spray mixture is normally used, the usual rate of application being 1 lb. DDT and 0·25 lb. γBHC per acre; recent trials have shown that the concentration of BHC in the mixture can be reduced. Four to eight applications are required at weekly intervals from the time of the initial stainer migration.

Using the best cultural methods, plus insecticides, a yield of over 2200 lb. seed cotton per acre has been recorded at Samaru, and at several other stations 1000–1500 lb. per acre have been obtained. Extension of these results beyond the experimental stage is taking place on the early stages of cotton multiplication and on several settlement schemes.

The cotton stainer referred to above is the " spotted " form of *D. superstitiosus*; the " banded " form originally described under this name which may be a distinct species, is found in the central and southern areas of Nigeria. Alternative hosts of the stainer are numerous and widespread. At Mokwa in 1958, for example, adults were present on cotton, cultivated hibiscus and *Sterculia* sp. in January. In February they were breeding on *Ceiba pentandra* (kapok), *Bombax buonopozense* (red silk cotton) and *Adansonia digitata* (baobab). After dispersal from *Bombax* in May, and from the other trees in June–July, breeding occurred on millet in July. Adults migrated into cotton, hibiscus, and *Urena* in August, and started to breed again on baobab and *Sterculia*. They were also recorded on sorghum from October to November. At Samaru there is a puzzling absence of cotton stainers on tree hosts during the early part of the year, before they appear in large numbers on silk cotton trees in mid-March. Three dipteran parasites have been identified on stainers taken from millet: *Bogosiella fasciata* (F.), *Alophora nazalis* Bez., and *Sarcophaga villa* Curran.

The biology of *D. watersi* has already been described; recent observations have confirmed that emergence from long term pupae is not always bi-modal. In 1959, for example, moths emerged in small numbers until a pronounced maximum occurred in early October. The pattern of emergence was very similar to that obtained from catches made in a light trap.

An important parasite of red bollworm is *Carcelia evolans* (Wied.); this appears to be so well adapted to its host that it might be host-specific and distinct from morphologically similar flies parasitising other hosts in East Africa. It is believed that it diapauses as a first instar larva within the pupa of the overwintering bollworm; development continues when diapause is broken, and the full grown larva leaves its host and makes a small hole in the earthern cell before a puparium is formed, to facilitate the exit of the fly when it emerges.

The rate of parasitism of red bollworm probably averages 10 to 15 per cent. and there is an obvious danger that the use of insecticides may reduce this. Another undesirable effect of spraying is that it favours the increase of a red spider mite, *Oligonychus gossypii* Zacher, during October and November; up to the present the effect of this mite on yield has not been serious.

Grain Storage

During the past two years investigations on the small-scale storage of grain by peasant farmers have been intensified, to enable a simple, safe and economic method of reducing losses by storage pests to be formulated. Over a large area of Northern Nigeria, guineacorn, *Sorghum vulgare*, Pers. and millet, *Pennisetum* spp., are stored on the head in mud, or less commonly, grass, " rumbus." The grain is used as required, the average period extending for six or seven months from harvest. Insect damage increases during the rains, and is heavier in regions of higher rainfall.

It has been shown that, over a period of ten months, mixing a 0·5 per cent. lindane dust at the rate of 2 parts per million by weight with guineacorn gives a considerable degree of protection against insect attack. At Samaru, for example, this method reduced the number of damaged grains from over fifty to less than two per cent. Many of the important storage pests, *Tribolium* spp., *Sitophilus oryzae* (L.), *Cryptolestes* (*Laemophloeus*) *ferrugineus* (Ol.)

Sitotroga cerealella (Ol.) have been found in guineacorn and maize heads in the field at harvest.

A comprehensive series of trials is now in progress at twenty stations in the Region; these are testing the effect on storage pests of the admixture of lindane dust at 5, 10, and 15 p.p.m. over a period of nine months. Particular attention is being paid to the problem of toxic residues after the grain has been prepared for consumption. It is hoped that provisional recommendations on the use of insecticide admixture with grain will be issued by the end of 1960.

An experiment on the underground storage of grain in a concrete "Argentine Tank" was completed in March, 1960. This was done on behalf of the Northern Region Marketing Board to test the use of this type of storage as a famine reserve. The tank, which was sealed in 1955 with a cover of bituminous roofing felt, contained 130 tons of guineacorn. After five years' storage the major part of the grain showed little deterioration; about one per cent. had been damaged because water had entered through the roof. It was confirmed that this type of storage would be effective if the tank could be adequately sealed; a concrete roof would probably be better for this purpose than roofing felt.

Citrus Pests

The most common scale insect on citrus is *Coccus hesperidum* L.; *Lepidosaphes gloverii* (Pack.), *L. beckii* (Newm.), *Parlatoria citri* Mck., and *Chrysomphalus ficus* Ashm. occur in the riverain provinces. *Coccophagus pulvinariae* Compere is an important parasite of *C. hesperidum.*

Ants found in association with scale insects include *Oecophylla longinoda* (Latr.), *Campanotus* spp., *Crematogaster* spp., *Pheidole* sp., and *Mymecaria* sp. Elimination of attendant ants reduces coccid populations; with tree-living ants a foliage spray of 1 per cent. dieldrin gives good control; for ground-living ants, trunk-banding with a mixture of dieldrin concentrate and Albolinium is adequate.

Other citrus pests include the orange dog butterfly, *Papilio demodocus* Esp., false codling moth, *Argyroploce leucotreta* Meyr. and an Aphid, *Toxoptera aurantii* (B.d.F.).

Harvester Ant

The harvester ant, *Messor barbarus* L. var *nigra* Andre, is found in the drier parts of the Northern Region; it is a nuisance in experimental areas, and where establishment of grassland is required. Good control has been achieved by treating pests with weak aldrin (0.2 per cent.), plus ringing of nests with 2 per cent. dieldrin dust.

Groundnut Rosette—Northern Provinces

Rosette disease is seldom troublesome in the Sudan Zone of Northern Nigeria, where the bulk of the export crop is produced, or in the Sub-Sudan Zone. In the wetter parts of the Northern Guinea Zone, however, the disease frequently reduces the yield from late sown groundnuts. With sowings made in late May, flights of the aphid vector, *Aphis craccivora* Koch., have been recorded in July and October, probably due to migration from alternative hosts. With late sowing, an additional migration occurs and the Aphids remain in the crop until harvest. During the 1959–60 dry season the vector was found on several alternative hosts; these include *Sesbania sesban* (L.), Messil, *Indigofera* sp., *Alysicarpus glumaceus* (Vable) DC, *Vigna* spp. (including cowpea), *Cajanus cajan* Millsp. (Pigeon Pea), *Phaseolus vulgaris* Linn., *Euphorbia* sp. (? *E. convolvuloides* Hochst.) and *Synediella nodiflora* Gaettn. Cross infection studies are now in progress in an attempt to determine the source of infection within the crop.

Groundnut Rosette—Riverain Provinces

In the riverain provinces, where groundnuts are not yet a major cash crop, losses due to rosette can be heavy. Late sowing is more widely practised to avoid harvesting during the rains, which start earlier and persist later than in the north. As in the north, two main flights of Aphids occur, the first in May–June for early sowings, but in August–September for late sowing seed transmission of the virus has not been demonstrated; as centres of infection can be found in the crop within two weeks of sowing, it seems likely that small and virtually undetectable numbers of Aphids exist in the crop at this period.

At Mokwa no alternative hosts for the Aphid, other than volunteer groundnuts, have been found during the dry season.

As with other aphid-borne virus diseases in temperate regions, it has been shown that the early establishment of ground-cover is of great significance in controlling rosette. Once 50–60 per cent. cover has been established, the infection rate falls, and it never becomes serious after total cover has been established. With late sown groundnuts, cover is not more than 50 per cent. during the early infection, and only reaches a maximum of 90 per cent. at maturity.

Where symptoms of rosette were observed 4 weeks after sowing, there was virtually no yield; when symptoms appeared after 8 weeks, the yield was reduced by half; infection seen at 12 weeks caused no reduction in yield. It is therefore probable that, with a late planted crop, prevention of rosette infection during the first 8–10 weeks would result in control. Preliminary trials with Rogor, applied as a single dose at germination, indicate that protection can be given for nine weeks during the susceptible period.

2. REVIEW OF WORK CARRIED OUT BY THE VETERINARY TSETSE CONTROL UNIT, MINISTRY OF ANIMAL HEALTH AND FORESTRY, NORTHERN NIGERIA

Previous to 1954, tsetse eradication in Northern Nigeria was concentrated on riverine clearings directed against the vectors of human trypanosomiasis. In 1954 the Veterinary Tsetse Control Unit was formed so that more attention could be paid to the specific problems relating to trypanosomiasis of livestock.

The four main species of *Glossina* found in the Northern Region, *G. morsitans submorsitans* Newst., *G. tachinoides* Westw., *G. palpalis* (R.–D.) and *G. longipalpis* Wied., are all vectors of cattle trypanosomiasis. About one-fifth of the Region is infested by *G. morsitans* Westw., the savannah tsetse fly, and zebu cattle cannot survive in this area. *G. tachinoides* and *G. palpalis*, which infest vegetation adjoining rivers and streams, are found in about three quarters of the Region, and cattle can exist in close seasonal contact with these flies only when given frequent treatment with trypanocides. *G. longipalpis* is confined to localized areas in the southern part of the Region and, again, cattle cannot survive contact with this fly. It is only in the northern part of the Region, comprising about one-fifth of the country, that cattle can roam freely without the danger of being infected by tsetse. This also applies to other livestock such as horses, donkeys, sheep, and goats although the smaller animals, when confined to smaller villages surrounded by cleared farm lands, can, and often do, survive in areas further south.

The problem of tsetse eradication is thus of paramount importance to the wellbeing and expansion of the livestock industry in Northern Nigeria.

Surveys

The main task during the early years of the Unit's existence was to add to the knowledge already available relating to the distribution of tsetse. During the last six years, over 30,000 square miles have been surveyed in detail, and a more accurate tsetse distribution map has been compiled.

It is apparent from successive surveys, and from the increase in trypanosomiasis in cattle that there have been considerable advances of *G. morsitans* in recent years and belts have increased in size. It is difficult to determine the reason why these advances occur.

The most spectacular advance has taken place in one portion of the large central *morsitans* belt centred on Kaduna and Zaria, where an expansion of over 50 miles on a 40-mile front has taken place over the last 10 years. This advance is still continuing (Wilson, 1958; Maclennan, 1958).

During the course of the surveys much new information about the ecology of the various species has been collected. This was essential because eradication methods based on clearing vegetation have been replaced by methods based on the use of insecticides, and spraying must be highly selective to enable such schemes to be economically worthwhile.

Complications arise due to the variety of species, each of which require some modification of the basic spraying technique for eradication, and further modifications are required to deal with the same species when found in a different vegetational zone. Techniques have also to be modified according to the season.

Eradication of *G. morsitans* in the Sudan Savannah Zone

An elongated fly belt, covering parts of the flood plain and adjoining uplands of the Komadugu Gana river, about 120 miles long and, in places, up to 10 miles wide, and infested by *G. morsitans* (and *G. tachinoides*) has been practically eliminated after five years work. Eradication will be completed next year.

In the Sudan Savannah zone (Keay, 1953), the hot, arid climate during the dry season months of January to April compels the flies to retreat to shady forest clumps on the flood plains or river banks. The success of the scheme has depended on taking advantage of this marked seasonal recession and the technique has been to spray the tree trunks, on which the flies were observed to rest, with DDT wettable powder suspended in water using knapsack sprayers.

During the first year the concentration used was 50 per cent. DDT wettable powder diluted with water to 5 per cent. actual DDT. Trunks, branches, twigs, shrubs and thin-stemmed thicket vegetation were sprayed up to a height of about 8 feet. Two applications, at an interval of four weeks were made to certain foci, and it was assumed that a barrier clearing would be necessary to protect the reclaimed areas at the end of each wet season.

As the work progressed the concentration of the insecticide was reduced to 3·75 per cent. and later to 2·5 per cent. DDT. Spraying became more selective and is now confined to tree trunks 9 inches or more in diameter and only to a height of 5 feet. It has been found that one application is sufficient even to the denser foci. Reinvasion of fly into the sprayed area during the rains seldom exceeded half-a-mile; this reinvasion was more easily dealt with by respraying at the beginning of each season rather than by the creation of expensive barriers. Recent surveys have failed to reveal a single fly in the reclaimed area (Maclennan and Kirkby, 1958; Kirkby and Blasdale, 1960; Davies and Blasdale, 1960).

Eradication of *G. morsitans* in the Guinea Savannah Zone

Further south, near Shika, in the more humid Guinea Savannah Zone, an area of 37 square miles was sprayed with 3·75 per cent. DDT wettable powder in aqueous suspension, again during the dry season and using knapsack sprayers and ‘ motoblo ’ mistsprayers. The technique used was similar to the successful one employed further north, but the insecticide was also applied to the more dense leafy vegetation, especially in water courses.

Prior to spraying, the number of *G. morsitans* caught on fly rounds amounted to a total of 610 flies per month. Four weeks after completion of spraying the catch had fallen to 3 per month. The area was not completely isolated from the adjacent large *G. morsitans* belt and difficulties were experienced in preventing reinvasion of this block.

Following on this success in the Guinea Zone, a more ambitious project, covering an area of over 200 square miles, in western Bauchi Province, is now in operation. Application of 3·75 per cent. DDT wettable powder in aqueous suspension, is being applied again during the dry season. All water courses are sprayed but in the adjoining uplands attention is being confined to the *Isoberlinia doka* and *Isoberlinia dalziellii* woodlands which cover about a third of the area. They are very well defined and form a favourite habitat, especially the water courses inside these stands, into which *G. morsitans* make their annual retreat during the dry season.

The usual procedure adopted to determine the most economical technique is to spray a large amount of vegetation initially and gradually eliminate what are thought to be unimportant resting sites. The large tree trunks again seem to assume importance as essential resting sites and spraying in the greater part of the area is confined to these, but up to a height of about seven feet.

Observations made during surveys revealed that the underside of overhanging branches, at a height of eight to ten feet from the ground, were favourite resting haunts of *G. morsitans* during the morning. Spraying in one portion of the area is confined to these branches.

It is too early at this stage to assess long term results but the immediate effect on the fly population indicates that trunks and main branches of the larger trees, rather than leaves, twigs, thickets and shrubs are essential places of retreat, at least for one period during the twenty-four hours.

In the more southern portion of the Guinea Savannah Zone it was observed that, during the dry season recession of the fly, *G. morsitans* concentrate at the headwaters of streams forming the tributaries of larger rivers. The fringing forests of these streams are usually well marked and start at the point where the stream has its dry season source. It is here that the fly is found on the outside fringe of the thick riverine vegetation and wandering only to a small extent into the neighbouring open woodland. The concentration area thus forms an inverted " U " capping the source of the stream with the arms of the " U " spreading downstream on the outside fringe of the riverine vegetation up to about a quarter of a mile. The breeding pattern (pupal sites) also follows this conformation.

An experiment designed to eliminate the fly in the vicinity of Kontagora, by cutting down the vegetation in this concentration area, failed to effect eradication as the fly seemed to adapt itself to the vegetation and microclimate further downstream. The next step is to use insecticides rather than clearing.

Eradication of *G. palpalis* in the Guinea Savannah Zone

An experimental project at Kajuru, using various insecticides to ascertain which one could control *G. palpalis*, after a single application, during the wet season, demonstrated that dieldrin emulsion concentrate, at a strength of 4 per cent. was most effective.

This insecticide was applied to five miles of river where *G. palpalis* were being caught at the rate of 22 flies per patrol mile. The catch soon dropped to nil and remained so for four months when five flies were caught. This was presumed to be an invasion from a focus two miles away as during the following eight months, when fly rounds continued, no further flies were caught. Rainfall was measured for 20 days after spraying and averaged 0·33 in. per day.

Following on this experiment, the fringing vegetation of over 350 miles of rivers and streams in the Zonkwa area have been sprayed and the fly eradicated. Physical impediment by grass and water during the wet season has confined spraying operations mainly to the dry season. Various insecticides have been used and different techniques employed. A single application of 3 per cent. dieldrin, confined to one bank of streams and the narrower rivers, is completely eliminating the fly.

Eradication of *G. tachinoides* in the Sudan Savannah Zone

In some of the flood plains of the larger rivers it was noticed that during the dry season this fly retreats to certain favoured localised, well-wooded habitats, as distinct from the usual linear formation adopted on the smaller streams fringed by more even vegetation. In the Gongola valley an important grazing area has been made safe for livestock by cutting down vegetation in these localised spots. Farming the cleared areas prevents regeneration.

In the neighbouring drainage area of the Ine river the method has been altered to insecticide spraying. BHC, dieldrin emulsion concentrate and DDT wettable powder have all been used, but a single application of 3·75 per cent. DDT wettable powder in aqueous suspension, is the present standard method. This method depends on extremely accurate surveys as only the dry season survival foci are sprayed, while thickets and forest islands, where no flies are found, are ignored. Spray teams have had to retrace their steps to deal with fresh foci more often on this scheme than on any other. The infested streams flowing into this extensive food plain are also being sprayed but here the application of insecticide is more regular.

It is hoped to complete the project during the current season, the scheme having covered rivers and streams in an area of over 2,000 square miles.

G. tachinoides is also present on the main water courses in the area covered by the Komadugu Gana scheme. The trunks of the small, as well as the larger, trees on the banks of these rivers are sprayed, also some of the more dense vegetation. Although this project covers an isolated *G. morsitans* belt, the *G. tachinoides* infestation is not isolated at the southern end where eradication work started. Reinvasion took place during the first year, but the clearing of a ruthless barrier (by the Ministry of Health), and respraying the invaded portion, has now isolated the area.

Eradication of *G. longipalpis* in the Guinea Savannah Zone

Surveys have demonstrated that when a few *G. longipalpis* are caught, somewhere within a radius of about two miles from that point a dense focus of the fly usually exists. Breeding also seems to be confined to these foci and large numbers of pupae can be found, usually under fallen logs. Previous to the discovery of this system of localised fly concentration hardly any breeding sites had been found in Northern Nigeria. Eradication of these concentrated foci should not be difficult but as, in nearly every case, the surrounding vegetation is infested by other species of tsetse, elimination of *G. longipalpis* alone would not be an economic proposition.

Future of Tsetse Eradication

Methods relying solely on clearing vegetation have been abandoned; the future of tsetse eradication depends on the use of insecticides. We already possess sufficient knowledge to be able to forecast with a fair degree of accuracy which insecticide and type of sprayer are necessary for a projected scheme, what technique of spraying should be adopted and, to a lesser degree of accuracy, what the costs are likely to be. Efforts must now be concentrated to determine which of the many sprayers and insecticides which have been used with success are the most economical and efficient, and how to develop our techniques further so that as little vegetation as possible is sprayed, compatible with complete elimination of the fly.

Our main problem at present is to protect reclaimed areas from reinvasion by fly from adjoining infested country, as reclamation using insecticides does not destroy the conditions necessary for the fly's existence as was the case when cutting down vegetation was the main weapon used. Clearing of large barriers is expensive while insecticide barriers are not permanent. The obvious solution is to embark on bold, large scale schemes with rapid reclamation of complete belts as the objective.

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3. WORK BY MINISTRY OF HEALTH—NORTHERN NIGERIA

The entomological research work carried out by the department in this period has been mainly concerned with the control of the insect vectors of human trypanosomiasis, onchocerciasis, and malaria.

Sleeping Sickness Service

By 1954, there was a pressing need for a new technique of control of *Glossina palpalis* (R.-D.) and *G. tachinoides* Westw. to replace the classical method of riverine vegetation removal. The latter was becoming uneconomic due to the continual rise in labour costs, while zones of such dense vegetation were now being encountered that, at times, clearing was a physical impossibility. There was also an increasing difficulty in maintaining the cleared areas.

One attempt at cutting costs was Nash's " obstructive clearing," (Nash and Steiner, 1957) whereby the river course was physically obstructed by vegetation, with a view to denying *G. palpalis* its normal flight line. While the W.A.I.T.R. experiment was successful, further field trials were considered desirable by this department. Two extensive trials were therefore carried out in 1955–57, one in the North Guinea Savannah zone, and the other in the South Guinea Savannah. The results of both trials indicated that while the method worked in small tributaries, over a large area too many limiting factors were involved to make it generally acceptable. A suggestion that obstructive clearing might be used on a limited scale as a protective measure (*i.e.* to reduce man-fly contact at possible points of contact) was proved to be of no value.

The main work has been the establishment of methods of insecticidal control. In 1955, an attempt was made to eradicate tsetse from 8·5 miles of river (isolated by clearings) in the southern Guinea Savannah zone, by spraying with DDT. Three treatments at monthly intervals reduced but did not eliminate the fly population, but five treatments at two week intervals in 1956 did eradicate both *G. palpalis* and *G. tachinoides* for four months, after which the fly population began to become evident again. This was considered to be most likely due to re-invasion, in spite of the clearings. Treatments were of either 2·5 per cent. or 5 per cent. DDT suspensions in water, using 50 per cent. wettable powder as bases. Applications were made with knapsack sprayers and all treatments were carried out in the dry season.

It was obvious that wettable powders were not suitable for this area, where high humidities are experienced even in the dry season, and where the latter may be interrupted by odd storms. In 1958, a small trial on 4·5 miles of river was carried out, using 4 per cent. emulsion of dieldrin in water (from 20 per cent. emulsifiable concentrate). Approximately 10 gallons of concentrate were used per mile and this included some high forest. Immediate success was obtained, which was maintained throughout the following year. In 1959, 56 miles of river in the same area, again including some patches of high forest, were given one application of 4 per cent. dieldrin emulsion, at an overall rate of 5·6 gal. of concentrate per mile, again with immediate complete success which has been maintained for over a year. An insecticidal barrier made by giving 2 miles of river one treatment of 4 per cent. dieldrin has remained " fly-proof " for one year, although open at one end to possible re-invasion. Wet season spraying, again with 4 per cent. dieldrin, has been shown to be possible.

In the Northern Guinea Savannah and Sudan Savannah zones where *G. tachinoides* is predominant, work with DDT wettable powder has continued. In these zones, a dry season of six months or more can be expected, with extremely low humidities, and a great range of temperature. These factors tend to keep tsetse restricted closely to the watercourses. In 1957 a field trial was carried out on 37 miles of river, previously isolated by clearing. Two applications of 5 per cent. DDT in water were made, and nil catches were recorded in the second month after spraying. Although solitary flies were caught on two occasions during the remainder of the year, it was considered likely that these were immigrants introduced by nomadic cattle. Work has continued in this area, 180 miles of river being sprayed in 1958, and 394 miles in 1959, in both cases making only one application of 3 per cent. DDT. The main difficulty that has arisen is the prevention of re-invasion. This seems most likely to be due to cattle movements, over which there is no control.

Since 1958, investigations have been continuing in the wide flood plains of the River Hadejia, towards the northern limit of *G. tachinoides*, where one of the main endemic foci of human trypanosomiasis occurs. Here there are belts of extensive woodland (often with *G. morsitans* Westw. as well), through which tsetse range. It has been confirmed that both species tend to concentrate mainly in the watercourses during the late dry season, so that a relatively small proportion of the total area requires treatment. Tests on DDT persistence are now being carried on. Effective persistence of 60 days (*i.e.* considerably longer than the average pupal period) has been confirmed, and it is anticipated that 80–100 days will be obtained.

An experiment using 1 per cent dieldrin emulsion against *G. palpalis* in the Northern Guinea Savannah proved unsuccessful, but a repeat application with 2 per cent. dieldrin, gave complete control. Two per cent. dieldrin was also successful against *G. tachinoides* in the Sudan Savannah.

Several experiments with plant poisons of the hormone type have been made, with a view to the destruction of the riverine vegetation. Results were so inconsistent as to make any further work unwarranted.

Simulium Control Unit

This unit was formed in 1954 under the supervision of an entomologist to carry out surveys to determine the geographical distribution of *Simulium damnosum* Theo. vector of onchocerciasis, and also to investigate the possibility of controlling this species.

Since then the major part of Northern Nigeria has been surveyed and a fairly comprehensive picture of the distribution of the various species of *Simulium* has been built up. In general, *S. damnosum* has been found to adhere closely to the geological picture in that its distribution coincides in the main with pre-Cambrian outcrops and is very seldom found in the sedimentary areas. The majority of breeding grounds are to be found towards the edge of these rocky plateaux where the rocky streams tumble down to the sedimentary river plains.

The greater part of the work of the Unit has been confined to the Abuja Control Scheme. Some 1,200 sq. miles in Abuja Emirate, Niger Province, form the site of this scheme. The area is dominated by three parallel, westward-flowing rivers, flowing from the southern edge of the central plateau into the Niger valley, and all of which support breeding of *S. damnosum* in considerable numbers throughout the year. These three rivers, the Tapa, Iku and Usuman are treated with DDT at seven larviciding points distributed thus:—the Tapa 2, the Iku 1 and the Usuman 4 points. Treatments were at the rate of 1 part per million DDT/river water for a period of 30 min. Treatments take place once a week for a period of 10 weeks. Details of the treatment are best summarised thus:—

Year	*Period of larviciding*	*Formulation used and ppm*	*Mean Fly Catches*†						
			June	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1955	Pre Treatment	—	3·29	8·28	15·96	16·75	8·53	2·89	1·19
1956	March–May	DDT/Diesel, 1–2*	0·10	0·21	0·32	0·14	0·93	0·16	0·06
1957	Feb.–April	DDT/Diesel, 1	0·42	2·07	2·93	2·12	1·22	1·08	0·24
1958	May–Aug.	Emulsion, 0·5	0·14	0·15	0·04	0·5	0·9	0·23	0·21
1959	June–Aug.	Emulsion, 0·5	0·22	0·62	0·0	0·78	1·62	—	0·14

* Constant dose of 28 lb. DDT Technical in 22 gal. diesel oil applied regardless of flow.

† Flies per boy-hour.

The fly catches compare very favourably with the pre-treatment figures showing that a fair degree of control has been achieved. It has been found that treatments carried out in the beginning of the wet season (1956, 1958, 1959) are more successful than dry season treatments (1957) possibly due to the greater flow providing a better carrier of the insecticide.

Skin snip surveys show an overall incidence of onchocerciasis of 74 per cent. in the population. An assessment survey is being carried out at the moment and it will be interesting to see if there has been any reduction in incidence of this disease since control started.

In addition to the above, some work has been done on the infection rates of *S. damnosum* with *Onchocerca volvulus*. In the rain, the results have shown that the infection rate is highest at the beginning and at the end of the wet season when the fly populations are moderate, than in the height of the wet season when the fly population is at its maximum. Rates of between 5–15 per cent. infected flies have been found. It has also been found that older, and therefore more likely to be infected, flies tend to bite at mid-day whilst the young flies tend to bite in the morning and evening. Hence the risk of infection could be greatest at mid-day in the early and late rains.

Work on *S. bovis* De Meillon which is an intermittent man-biter in some parts of Nigeria has shown that in some cases 6 per cent. of the flies are infected with filarial larvae. Whether or not these are *O. volvulus* is not known. It is considered, however that *S. bovis* is of no real economic importance due to its timid biting habits and limited distribution.

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NORTHERN RHODESIA

REVIEW OF WORK ON TSETSE CONTROL

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Since 1953 there has been a steady increase in staff employed in Tsetse Control in the Territory. At that time, the European staff consisted of 2 Entomologists and 9 Tsetse Control Supervisors, whilst at the end of 1959 this had expanded to 6 Entomologists and 23 Tsetse Control Supervisors, including four officers engaged in Tsetse Control operations connected with the resettlement of Africans displaced from their normal habitation by the Kariba Hydro-electric project. The number of African staff has also shown a proportionate increase and is now over 500, including all categories of Tsetse Control Guards, Fly picket Orderlies and Hunters, engaged in Tsetse Control measures in some 22 separate localities.

By 1955 the territory-wide survey of tsetse distribution had been completed and the limits of all fly belts mapped. It was found that some 90,000 square miles of the territory were invested by *G. morsitans* Westw. with *G. pallidipes* Aust. superimposed in certain localities on the primary infestation in density varying from codominant over large tracts of country in the Luangwa and lower Zambesi valleys to restricted local occurrences in the Mumbwa and Kawambwa districts. Features of note were the number of localities in which the presence of *G. pallidipes* had been missed in the past and the number of times this species was discovered outside its classical habitat.

Of the remaining two species found in the Territory, *G. brevipalpis* Newst., with its wide but strictly localised occurrence in the Northern and Eastern Provinces, is of no economic significance at the present stage of development of the country, whilst *G. palpalis* (R.D.) presents a control problem only on the southern shores of Lake Tanganyika.

No evidence of the presence of *G. palpalis* on any of the water-courses forming part of the Zambesi Basin drainage was found, and it is extremely unlikely that this species occurs on this river system, at least in Northern Rhodesia.

The infestation by *G. morsitans* can be divided roughly into seven belts, some of which do not show continuous fly distribution, but have been subdivided into a number of portions of varying dimensions by a variety of outside factors. The two largest continuous belts, each of some 30,000 square miles in extent, are the far eastern, associated with the Luangwa River, and the great western, associated for the most part with the Kafue River system; these two rivers being the two main tributaries of the Zambesi River running through Northern Rhodesia. A further and as yet restricted infestation existing on the Barotseland-Angola-Caprivi Strip border is a new development and has arisen as an extension of the fly population previously found in the Caprivi Strip.

The survey was of extreme importance in formulating a policy of Tsetse Control for, besides providing a wealth of data on the ecology of *G. morsitans* and *G. pallidipes* and their relationship to vegetational complexes, animal distribution and human settlement, it also gave a criterion against which future fluctuation of the tsetse population could be measured.

In 1954, data from fly rounds and pickets showed that there was a general overall increase in the density of *G. morsitans* populations. As the boundaries of the various *morsitans* infestations measure some 5,000 miles in length and over a large proportion are contained by no natural barrier, it was obvious that if the upsurge in fly population continued there was a great danger of the belts extending their bounds and encroaching into fly-free country. This did in fact occur in a number of localities of which the ones of major economic importance were Kalomo, Chisamba, East Lusaka, Mumbwa, North Mumbwa, Fort Jameson, Kawambwa, Machili and in Barotseland along the Mashi River. In many instances, the threat of encroachment had been anticipated and either investigations or active control measures were in force when it occurred. Even so, gains were made by the advancing fly before the tempo of the control measures could be increased to the extent necessary, first to hold the advance, and then to begin the task of ousting it from its new habitat.

Operations were often considerably hampered by the fact that the encroachment had taken place into regions which possessed a very light, scattered human population of insufficient density to have any effect on the extent or speed of the fly advances. The occupation of these areas by fly was of little moment, but as they were contiguous to country with denser human population in which cattle were herded, the effect on the incidence of bovine trypanosomiasis was profound. This meant that the advance had to be met in most cases by active control measures alone, without the aid of any natural barrier to fly encroachment or the effect of human settlement in a density sufficient to render the environment inimical to the continuance of an infestation by *G. morsitans.*

Prior to 1954, the policy of tsetse control in the territory may be said to have been the prevention of any deterioration in the fly position, the provision of land for resettlement when required and to reduce the incidence of trypanosomiasis (especially bovine) by active control measures against the nearest fly concentrations.

This policy, however, was affected by the considerable extent of the fly belts necessitating a piecemeal approach to the problem, the lack of Africans available for rural development and the infertility of the soil in many instances, and the proximity of the fly belts and pastoral areas being such that any small change in the extent of infestation in the former seriously affected the bovine trypanosomiasis position in the latter.

With the manifestation of the encroachment potential in 1954 and its continuation to the present time the approach to the problem had to be altered and more attention given to the maintenance of the *status quo*. To effect this a number of operations had to be started aimed at the prevention of encroachment or the elimination of the advance where encroachment had already taken place. All recognised methods of tsetse control were used, so far as it was economically feasible. The methods in use may be summarised as follows:

Discriminative Clearing

G. morsitans is capable of colonising many types of vegetation and consequently the plant species that must be cleared vary considerably in different localities. In Abercorn where this form of control is being used, following considerable success in the past, the clearing usually takes place in dambo edge ecotones or in well-defined drainage lines in *Brachystegia-Isoberlinia* woodland. At Machili, however, where the method is being employed to halt an encroachment of fly westwards towards Barotseland, the picture is completely different, as much of the area is characterised by *Baikiaea plurijuga* (Rhodesian teak) forest with associated heavy undergrowth on Kalahari sand intermingled with *Brachystegia-Isoberlinia* or mixed woodland and stretches of *Copaifera mopani*, pure or mixed with *Balanites*. The whole is dissected by dambo drainage lines which merge in the west with the plain associated with the Machili River. The teak forest will not harbour *morsitans*, but in general all areas of mixed vegetational communities do provide habitats of varying favourability. Discriminative clearing therefore has been for the most part carried out in the ecotones between the various vegetational complexes and along dambo edges and drainage lines. It was also discovered that pure stands of well-grown *C. mopani* presenting a " cathedral-like " appearance, were providing a complete habitat for *morsitans* which had not previously been found elsewhere in the territory. It was necessary to clear the whole of the latter vegetational type and the most economic way was found to be to burn the individual trees. The method is successful, but the encroachment potential has not yet been neutralised owing to the wide front over which it is manifest.

Discriminative clearing has as yet been the only method of attack used against an encroachment of mixed *G. morsitans*, *G. pallidipes* infestation north of the Great East Road. Here it was carried out not only by hand labour, but also by bulldozers dragging a chain between them. The latter method of clearing was found to be effective in suitable terrain and eliminated the problem of regeneration, but it is still more expensive than hand clearing. In this area, fly had advanced along definite access lines from the Luano Valley, for the most part consisting of river tributary valleys cutting through the broken hilly country of the

Luano escarpment. Once the plateau was reached, the fly attempted to fan out in the more suitable habitat which then became available to it. The clearing had, therefore, to be aimed first at the neutralisation of fly concentrations established on the plateau, and second at the destruction of the access lines, for, if these were allowed to remain, they would enable continual reinfestation to take place in the future. The operation is not yet complete, but results so far have been promising and it is believed that the main encroachment thrust has been halted.

At Kawanbwa, however, clearing which was designed to eliminate fly from an infestation of long standing, in order that more intensive rural development could take place, failed completely, and a limited advance of *G. morsitans* over a narrow front occurred after the operation had been started. It is now intended to begin game elimination throughout the area in an attempt to stabilise the situation.

All these measures have been carried out in uninhabited or very sparsely populated country and any effect on the fly population has been achieved solely by the methods in force. The indication of which portion of the habitat is to be attacked is given by regular fly rounds, and it usually proved that more than one vegetational complex has to be removed, though the presence of subsidiary foci often becomes apparent only after the primary focus has been eliminated.

Discriminative Clearing with Resettlement

The incorporation of settlement into an area in which discriminative clearing is being carried out is eminently desirable for reasons that are well known.

The method has been successfully used in the Mumbwa district in a campaign aimed at the control of human trypanosomiasis in a mixed *G. morsitans* and *G. pallidipes* infestation. Here a total population of some 6,500 under four chiefs was contracted into an area of over 300 square miles, situated in the edge of the Great Western Fly Belt. Those portions of the area which could not be cultivated at the outset, or which were completely infertile and yet were fly infested, were attacked by discriminative clearing.

The vegetation in the area is extremely complex and varies from open, short-grass *Brachystegia* woodland through mixed, tall-grass woodland locally known as Chipya, to dense thicket, either broken and clumped on termite mounds, or in continuous distribution in considerable tracts. The habitat of the two species of fly merged from one extreme to the other with a wide central portion in which both appeared to be able to find the appropriate ecological niche. The result was that the amount of vegetation which had to be cleared to achieve eradication of both species was considerably more than is necessary when only one form is involved.

Regeneration also provided a problem especially in the thicket of the *G. pallidipes* habitat, but reasonable control was obtained by the late burning of piled trash and as yet it has not been necessary to resort to the use of arboricides.

T. rhodesiense infection was soon controlled and no cases have been contracted in the settled areas in the past five years though the disease occurs regularly in itinerant hunters and honey gatherers who visit the untouched hinterland. Cattle have also been introduced into the areas occupied by all the chiefs and, with the aid of chemo-prophylaxis, are thriving.

In the northern portion of the Gwembe Valley, a part of the Zambesi Valley below the Kariba Dam site, numbers of the local African inhabitants who were displaced from their old village sites by the inundation of Lake Kariba have been resettled. The area to which they were moved had a light infestation of *G. morsitans* which is at present being attacked. Where the fly was found to inhabit vegetation on fertile soil, such as the alluvium associated with some of the minor tributaries, the discriminately cleared areas were later used for gardens by the villagers. Fly is now being eliminated in those portions of the valley which are unsuitable for cultivation, where it is usually found associated with drainage lines running through rocky, scrub-covered hills.

Discriminative Clearing with Game Elimination

In many instances it has been necessary to utilise both these methods of control in the same area, though the order in which they were applied, and the reasons for so doing, were often different.

In the Fort Jameson district, for example, game elimination within a prescribed perimeter has been the primary tsetse control measure for a number of years against *G. morsitans*, with co-ordinated settlement following as gains were made. Of recent years the rate of settlement was too low for the tempo of the control measures and tracts of land inside the perimeter were left unoccupied.

Heavy fly density occurred just outside the perimeter and infiltrated across it, masking the true fly distribution. It was considered unwise to extend the boundaries of the game elimination measures as this would have resulted in the dissipation of effort over more uninhabited land, and so in an attempt to resolve the situation, discriminative clearing was started in the heaviest fly concentrations beyond the perimeter and in any residual foci inside it.

In two sectors these measures were successful, but while the operation was still in progress encroachment took place in a further region within the perimeter which had been hitherto fly-free, necessitating the redistribution of the disposition of the hunters and the commencement of clearing in the new infestation. The operation continues.

In Kalomo, discriminative clearing was being used with considerable success to eradicate fly in uninhabited country bordering European farms. In 1954, however, *G. morsitans* in the belt to the north, which had been static for a number of years, began to encroach southwards outflanking the clearing on both sides. An attempt was first made to meet the advance by further clearing and an existing barrier clearing along the farm edges was widened to give protection until the encroachment could be halted, but it soon became apparent that it would be impossible to carry out sufficient clearing in the time available to obtain the desired effect over the whole front. As there was also evidence of an influx of game animals from the north, it was decided to change the method of attack. A six-strand fence of high tensile wire on *Afrormosia angolensis* poles was then constructed running along the watershed between the rivers draining to the north and those draining to the south over a distance of 58 miles. All game south of the fence was to be destroyed and in two years there has been a reduction of 97 per cent. in apparent density of the fly population. The fenced area is some 600 square miles in extent, and is completely uninhabited; any residual foci of fly which might persist in the area will be eliminated by either discriminative clearing or by the use of insecticides.

In the Namwala district 20 miles of game fence have been constructed to prevent the migration of game from the Kafue National Park on to the cattle grazing grounds on the flood plains fringing the Kafue River. A restricted infestation of *G. morsitans* was cut off by the fence on the " clean " side and this is in the process of being eliminated by the exclusion of game aided by the clearing of the main fly concentrations.

At Feira, the population of two chiefs was concentrated in the lower Luangwa Valley as far as its confluence with the Zambesi River in an attempt to control the incidence of *T. rhodesiense* infection attributable to a mixed infestation of *G. morsitans* and *G. pallidipes*. Game was shot out in the settled area between the Luangwa River on the east side and its escarpment on the west. Clearing was also carried out in the main foci of both species of fly and hunting continues at the present time to prevent the influx of game from the uninhabited country to the west. No cases of human trypanosomiasis have been recorded from the settlement since 1954.

In the Broken Hill district the combined method was used to remove fly from the outskirts of Broken Hill township. Eventually fly became restricted to a pocket on the shores of Mulungushi Dam to the east of the town. In the initial stages of the campaign, only dambo edges were cleared but this combined with the destruction of game was sufficient to eradicate fly. In the residual pocket however, the method was not successful and intensification of hunting activity produced no improvement in the situation. The mode of attack will therefore be changed to that described later in this account.

Game Elimination

The game fence in the Namwala district on the North bank of the Kafue River has now been in operation for 9 years, and the infestation of *G. morsitans*, which previously existed in the fenced area, has been eradicated. A second fence is now to be constructed to the north of the first using the original as a base line. In the first instance this fence will be sited as two separate bays which will be joined at a later date. The bays will provide more land for agriculture for the African population concentrated inside the fence and will also eliminate resident fly from the original fence line.

Discriminative Clearing Aided by Insecticides

This method has been used with considerable success in four separate localities, Mulungushi Dam (Broken Hill), Chingola, Chisamba, and Sinazongwe in the Zambesi Valley. The first two infestations of *G. morsitans* were isolated pockets cut off from the main fly belts by either natural recession of fly or by direct control measures. In Chisamba, the fly attacked was a salient of encroachment emanating from the Luano Valley as a mixed infestation of *G. morsitans* and *G. pallidipes* which had become established on the plateau, while at Sinazongwe an infestation of *G. morsitans* of long standing is in the process of being eliminated to accommodate Africans displaced from their original habitation by the Kariba Hydro-electric Scheme. Though the vegetational types varied considerably from place to place, the mode of attack followed the same pattern. In the first instance the main fly concentrations as indicated by regular fly rounds were cleared. To effect this, hand labour was used for the most part but in Chisamba a large amount of clearing was carried out by a combined team consisting of (1) bulldozers where suitable, (2) mechanical saws to fell trees too large for the bulldozers to uproot easily and (3) hand labour to remove smaller vegetation and especially termite mound thickets which were inaccessible to the tractors. This combination worked well for it enabled the bulldozers to operate with maximum efficiency and the minimum of free running time.

Once the clearing had been effected in the primary and the more obvious secondary foci, insecticides were applied in those areas where a light fly density persisted but where the vegetational complex which was providing the fly habitat was difficult to distinguish or formed a large portion of the vegetation as a whole.

The insecticide used was a 1·5 per cent. BHC solution in dieseline applied as a thermal aerosol by a Todd Insecticidal Fog Applicator, mounted on a Mercedes Benz Unimog or on a trailer towed by a Ferguson tractor or land rover according to the terrain. The insecticide was applied by following marked lanes at right angles to the prevailing air stream during the hours of darkness when temperature inversion occurred. The lanes were usually spaced at 200 yards apart, though the procedure could be altered at the discretion of the operator depending on the meteorological condition and wind velocities which were encountered.

A series of 5 applications were planned at a time interval decided by the length of pupal period and at the temperature prevailing. Between the applications the spraying area was sampled by as many fly rounds as possible and at the end of the schedule any portion in which fly showed up was treated by a restricted application in that particular locality. In certain cases residual insecticide, either 5 per cent. DDT wettable powder or 5 per cent. dieldrin emulsion, was applied to sectors of the area where the application of the aerosol was difficult or on roads or tracks where fly was found to congregate. It was found that an area of about 25 square miles in extent was a suitable unit for each application.

On Lake Tanganyika, a *G. palpalis* infestation has been controlled by a combination of lake shore clearing and insecticides. At the start of the operation clearing only was used, but regeneration of the woody species was so rapid that the clearing operation had to be carried on almost continuously. It was also found that *palpalis* could exist in beds of *Phragmites* which were impossible to eradicate. Attention was therefore turned to the use of insecticides, in the first instance applied as a thermal aerosol of BHC but latterly more attention has been given to the application of a residual spray of dieldrin. As only a section of the coast line is treated, the insecticidal applications have to be applied at regular intervals to prevent reinfestation. A mixed infestation of *G. palpalis* and *G. brevipalpis* in a remnant of rain forest known as Mbete Sacred Grove, the burial ground of the local chiefs, has also been eliminated by the use of insecticides.

Control of Traffic

The close proximity of fly to the outskirts of all pastoral areas results in the carriage of fly by travellers well beyond the bounds of the resident infestation and the consequent infection of cattle who would not otherwise come into contact with fly. Over recent years there has been a general trend in the territory for the migration of rural Africans into urban areas. The trend has been accompanied by a growth in the trade of rural products, especially food-stuffs, which are peddled in the townships, so causing an unprecedented rise in the volume of traffic passing through all rural areas. As some of the commodities are perishable speed in reaching the consumer is essential and therefore the pedestrian has been largely replaced by the cyclist and motorist. Both of these wander indiscriminately from fly-infested to fly-free country in collecting their wares, then head for the markets by the shortest possible route. This traffic is responsible for carrying fly over long distances and it is essential that it be controlled. An attempt has been made to do so by the delimitation of Tsetse Fly Areas under the Tsetse Control Ordinance Chapter 129 of the Laws of Northern Rhodesia and the imposition of regulations to provide for the canalisation and disinfestation of traffic throughout these areas. During the past year new legislation has been passed for the extension of powers under the ordinance to enable stricter control to be applied.

There have been two operations instigated expressly for the control of carried fly: the first on the East Chisamba-East Lusaka front where trypanosomiasis was occurring on European farms in fly-free country caused by fly carried on travellers or by the uncontrolled movement of cattle which, when infected, disseminated the disease by acyclical transmission. The situation was resolved by the fencing of alienated land from Native Reserve and Trust land and the daily patrolling of the fence line, all traffic across the fence being confined to picketed authorised paths. The action together with a thorough chemotherapeutic campaign in the herds of cattle resulted in the virtual elimination of trypanosomiasis from the farm area.

The second operation which is at present in process of being implemented is designed to control fish traders operating in the Kafue Basin Tsetse Fly Control area and will again consist of the canalisation of traffic and the enforcement of the regulations by a system of mobile patrols.

Experimental Work

In Northern Rhodesia field research is incorporated in most tsetse operations consisting of investigations into the various methods of applying insecticides and arboricides, bush clearing techniques and the correlation of fly distribution to its ecology. Blood meals of tsetse flies caught on the fly rounds are collected and forwarded for analysis to the Lister Institute of Preventive Medicine and blood slides from animals killed in control measures are also examined as a routine. There is no fundamental research carried out as neither the staff nor facilities are available; instead, the findings of both the East and West African Research organisations are taken and an attempt is made to apply them to local conditions.

NYASALAND

1. AGRICULTURAL ENTOMOLOGY

By R. C. H. SWEENEY

Government Entomologist

After a vacancy of some 18 months, Mr. E. L. Drake arrived from the United Kingdom in November 1952 to take up the appointment of Government Entomologist. He left Nyasaland in July 1955. Dr. G. W. Heath came in November 1956 and left the country in June 1959 on resignation. Mr. R. C. H. Sweeney was appointed to the post on his return from leave in January 1960. There was no Government Entomologist, therefore, during the season 1955/1956 or from July 1959 until January 1960.

Research work on insect pests of cotton in Nyasaland has been reviewed separately as part of the Cotton Pest Research Scheme report (see p. 271). Work on other pests is summarised below.

Maize Stalk-Borers

Busseola fusca (Fuller) proved to be the commonest species. An experiment designed to test the influence of planting date and the effectiveness of DDT as a control of this and other species of borers was carried out on four different sites in highland areas. At only one of the sites was the infestation sufficiently pronounced to make the experiment a success and here there was a significant increase in yield on the insecticide plots. Early planted maize gave a better yield on all sites.

White-stem Borer

Excellent control of *Anthores leuconotus* Pasc. in coffee was obtained by painting the stems with dieldrin emulsion following the advice of the Lyamungu Coffee Research Station, Tanganyika. This is now standard practice.

Coffee Bug

An outbreak of *Antestiopsis* was controlled by using 5 per cent. DDT dust at 20 lb. per acre. DDT emulsions and malathion are now being used experimentally.

Termites on Tea

A randomised block experiment to test dieldrin and chlordane emulsions for the control of termites on tea was laid down. All the treatments were significantly better than the control but there was no significant difference between treatments. Dipping the aerial portions of the stumps in Dieldrex 15 at a dilution of 1 : 11 was considered to be the best treatment and gave effective protection to young tea stumps for at least six months.

Tobacco Root-Knot Eelworm

An experiment using Unifume (sodium n-methyl dithiocarbamate) was carried out against *Meloidogyne javanica*. A good control was obtained and there were no phytotoxic effects.

2. REVIEW OF TSETSE FLY WORK

By B. Steele

A survey of the tsetse position in the Protectorate with the aid of Colonial Development and Welfare Funds was completed in 1954 (" Report on the Distribution of Tsetse Flies in Nyasaland," B. L. Mitchell and B. Steele, Government Printer, Zomba, 1956). The main conclusion of the report, accepted by Government, was that the tsetse situation was not immediately serious and did not warrant expenditure on direct action for eradication. A recommendation that the tsetse infestation should be progressively reduced by canalisation of the inevitable expansion of human activity in the country was also accepted but has proved difficult to put into effect.

Since the survey, tsetse work has consisted mainly in resurveying the widespread areas of infestation by *Glossina morsitans* Westw. with a view to making recommendations in relation to agricultural expansion and also to keep track of changes in the tsetse population. At the time of the survey tsetse populations were at a low ebb. By 1957 there were signs, both from surveys and records from the fly decontamination posts, of a recovery, but a decline subsequently set in again. This decline, which has resulted in a reduction of many of the infected areas, is believed to be related to a recent succession of prolonged hot dry seasons with delayed starts to the seasonal rains towards the end of the year.

Human trypanosomiasis is practically absent and animal trypanosomiasis is a serious problem only in the extreme north, in Karonga District, and in the extreme south, in Port Herald and Chikwawa. In Karonga, the vector is *Glossina brevipalpis* Newst. and a campaign of eradication, based on clearing foci of infestation in densely wooded hill gullies over the past few years has resulted in a reduction of fly catches on regular patrols by well over 95 per cent. Trials of gammexane applications with " Swingfog " machines and, more recently, dieldrin from " Motoblo " machines are being carried out with a view to dealing with the persistent pockets of infestation.

In Port Herald and Chikwawa, possible direct sources of infection are *G. morsitans* carried from the border areas and *G. pallidipes* Aust. carried by trains from Mozambique. Studies showed that trypanosomiasis infection was much more widespread than the feasible range of these carried flies. Subsequent veterinary investigation showed that drug resistance, movement of cattle and possibly mechanical transmission were probable contributory factors in spreading the disease. A veterinary campaign for elimination of the indirect infections by drug treatment is now in hand and should lead to a simplification of the picture of disease distribution and a better understanding of the part played by direct infection from tsetse flies.

SEYCHELLES

REVIEW OF THE WORK IN ECONOMIC ENTOMOLOGY

By I. W. B. Nye

Colonial Pool of Entomologists

During the period under review there was no entomologist stationed in Seychelles from 1954 to 1958. Early in 1959 Dr. I. W. B. Nye was seconded from the Colonial Pool of Entomologists and concentrated on further research into the control of *Melittomma insulare* Fairm.

M. insulare is the main pest of coconut palms. The mechanical damage, caused by the larvae boring into the base of the palms, is itself very slight but each tunnel is preceded and surrounded by a zone of tissue affected by bacterial organisms with which the larvae are always associated. These areas gradually spread in all directions and coalesce, particularly in the moister central part of the trunk having relatively fewer vascular bundles. Once attacked by the micro-organisms these diseased areas can never recover and they gradually degenerate into brown and finally black rotten wood which in its turn breaks down, eventually leaving an empty cavity in the base of the trunk.

Previous control measures were based on partial excavation of the infested portion of the trunk, insertion of paradichlorbenzene in the cavity and mounding up of the base of the palm so as to form a fumigation chamber. This treatment has been found to be only partially effective, the majority of the fumigated palms still contained heavy infestations and the closed cavity formed an ideal environment for the associated rot which continued to spread throughout the boles. In the treatment now recommended and being carried out on a large scale, the infested and rotting tissues are gouged out through an opening kept as narrow as possible, particularly at ground level—the weakest point. All bared wood is then thoroughly painted with a mixture of 60 per cent. coal-creosote and 40 per cent. coal-tar. Within half an hour the larvae can be seen hanging tail first out of their tunnels, dead. The results obtained show that almost complete elimination of this pest is being achieved (Nye, 1959).

Rhinoceros Beetle—*Oryctes monoceros* (Ol.)

Though prevalent throughout the islands comprising the Seychelles group, this species does not cause severe damage except in the island of La Digue.

Scolia ruficornis F. was introduced from Zanzibar from 1949 to 1951 and has become established in one small island. Subsequent efforts to spread these parasitic wasps to other islands have been made, but no evidence that they have become established has been obtained.

Pyrophorus pellucens Eschscholtz, a large luminous Elaterid having a carnivorous larva, was imported from Trinidad in 1954 and liberated, but none have been recovered since.

Scale Insects and Mealy Bugs

Once the most important pest of coconuts and coffee, scale insects have been kept under effective control by coccinellid predators introduced from East Africa and India over twenty years ago.

Pseudococcus adonidum (L.), the long tailed mealybug, was taken at Poivre and Darros islands in 1959 for the first time in the Seychelles. Consignments of a coccinellid predator, *Cryptolaemus montrouzieri* Muls., and a minute parasitic wasp, *Tetracnemus peregrinus* Comp., were received from California but it is not yet known whether they have become established.

Citrus Black Fly—*Aleurocanthus woglumi* Ashby

This pest suddenly appeared in 1955 and spread rapidly. Consignments of the parasitic Eddy wasp, *Eretmocerus serius* Silv., were obtained from Jamaica and liberated in the same year. In 1956 effective control was achieved and this has continued.

Banana Weevil—*Cosmopolites sordidus* (Germ.)

This is a minor pest and during the period 1952–1954 consignments of tiger beetles, *Hololepta* (*Leionota*) *quadridentata* (F.), *H.* (*L.*) *colombiana*, Mars. and *Plaesius javanus* Erichs., were received from Trinidad. There has been no evidence that any of these species has become established.

Other Pests

It is of interest to record that apart from birds and the giant *Achatina* snail there are very few other pests of agricultural importance. Cinnamon and vanilla, which hold second and third place to copra in the list of exports, have no insect pests. Coffee is to a very small extent troubled by the green scale, *Coccus viridis* (Green), but this is for the most part kept in check by coccinellid predators. Other coffee pests are absent. Tobacco and crucifers grown mainly in smallholdings are attacked by leaf-eating and leaf-mining Lepidoptera. Control is achieved by lindane wettable powder. Sugar cane and cereals, including rice, are free of stalk borers and shoot flies. Cashew, castor and cotton, all of which grow wild and are not cultivated, appear to be free of pests.

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SOUTHERN RHODESIA

TSETSE FLY IN SOUTHERN RHODESIA

By J. Ford

Director, Department of Tsetse and Trypanosomiasis Control and Reclamation

In 1955 a Commission of Inquiry was set up to investigate trypanosomiasis control in the Territory, particularly with the object of investigating methods other than that of game destruction as the principal means of controlling animal trypanosomiasis. The Commission resulted in the establishment of a new Department of Tsetse and Trypanosomiasis Reclamation and Control as well as of a Trypanosomiasis Control Section of the Veterinary Department. The two units operate in close collaboration. It was realised that game destruction could not cease immediately; staff would have to be trained in alternative methods and the change could only be gradual. Nevertheless, between 1954 and 1959 the number of game destroyed yearly was reduced by well over 50 per cent. During the same period control of *Glossina* by use of bush clearing, especially in conjunction with settlement, and by the use of insecticides has increased accordingly. On the Veterinary side the closer control over cattle adjacent to fly belts by the Trypanosomiasis Control Section provides a valuable index of change in the tsetse situation.

The principal change in tsetse distribution has occurred in the Sabi Valley in the south east of the Territory. Here there has been an advance of both *G. morsitans* Westw. and *G. pallidipes* Aust. to the west and south. This is the right flank of an extensive spread of these species towards the Limpopo valley mostly located in Mozambique. A recent operation in which riverine vegetation was sprayed with a 3·6 per cent. solution of dieldrin seems to have been successful in temporarily eliminating one salient from this advance which developed in the Lundi River. Bulldozing of essential vegetation is being used to create a permanent vegetational barrier in the area. In the Zambesi valley, defence against tsetse movement is still largely controlled by game destruction between fences—erected around the periphery of the belt. In general, the Zambesi belt has remained stable, though operations in the Urungwe area, the scene of an advance in 1951–52, have resulted in a recession. Here shooting, bush clearing and insecticides all played a part and cattle are being re-introduced into areas evacuated in 1952. The Zambesi fly belt is also suffering a reduction in size owing to the flooding of the Kariba Lake which will, eventually, drown about 1,300 square miles of tsetse infested bush. Insecticidal fogging from aircraft was used successfully in two areas required for human occupation as a result of the Kariba Dam operations. In the north east of the territory the invasion of *G. morsitans* from Mozambique, which began in 1950, has been controlled and only a small salient of permanent infestation remains.

On the eastern border of the territory, where a long established barrier clearing controls the spread of tsetse from Mozambique, four species of *Glossina* have now been collected, *viz.*, *G. pallidipes*, *G. brevipalpis* Newst., *G. morsitans* and *G. austeni* Newst. In the wet season of 1958 crossing of the barrier by occasional tsetse resulted in an incidence of trypanosomiasis in adjacent farms higher than in any year since 1943. In 1959, spraying of the bush edge of the clearing with dieldrin was followed by a year more free of infection than any since recording began. Infections in farms opposite unsprayed portions of the clearing supported the view that the insecticide treatment had prevented tsetse from crossing the clearing.

A new field research station, as yet not completed, has been set up at Rekomitjie in the floor of the Zambesi valley about 30 miles east of the Chirundu Bridge on the Great North Road. This replaces the old Field Research Station at Kariangwe, which had the disadvantage of excessive remoteness. Investigations being carried out include studies of the resting sites selected by *G. pallidipes* after feeding; the diurnal behaviour cycle exhibited by hungry tsetse; the infection by various groups of trypanosomes of the wild tsetse populations.

Elsewhere investigational work includes (a) the large scale mapping of tsetse habitat distribution from aerial photographs, as a basis for planning control operations; (b) the collection of blood meals from wild populations of tsetse for analysis at the Lister Institute of Preventive Medicine and (c) the collection of pupae of *G. morsitans* and *G. pallidipes*, both as a study of seasonal changes in breeding sites and as a means of supplying puparia for work being carried out on tsetse physiology and behaviour at the University College of Rhodesia and Nyasaland.

TANGANYIKA

REVIEW OF ENTOMOLOGICAL WORK

By A. C. Evans

Chief Research Officer, Department of Agriculture

Organisation and Staffing

Department of Agriculture:—Four entomologists are on the staff of the Research Division, one is stationed at the Coffee Research Station and the others at three out of the four Regional Research Centres. At the fourth Centre an Entomologist of the Empire Cotton Growing Corporation was stationed. These officers are also concerned with specialist advisory work. Department of Veterinary Services:—Three officers are concerned with tick surveys in relation to disease and a fourth with tsetse research.

FIELD CROPS

Maize and Sorghum

Stalk borers, *Busseola fusca* (Fuller), aestivate during the dry season in stalks retained as cattle food. Control by destruction of this material is not practicable but it has been found that satisfactory control of first generation larvae can be achieved by the application of 2·5 per cent. DDT dust into the funnels of the plants at a rate of 5 lb. per acre per application. Three to four applications may be required.

Groundnuts

A variety, Asiriya Mwitunde, has been selected which shows field resistance to Rosette disease. The variety is as susceptible to the disease as any other variety tested but resistance mainly lies in the very low rate of infectivity of Aphids bred up on diseased plants thus minimising the usually crippling effects of secondary spread within the crop.

Castor

Mirids and Pentatomids cause severe damage to buds and developing fruit. Frequent applications of insecticides gave only a low measure of control since the buds and fruits drop if damaged even slightly.

Pyrethrum

Thrips, *Thrips tabaci* Lind., can cause considerable damage at times but control with DDT sprays is practicable. Melolonthid larvae can also be troublesome but can be controlled with soil applications of BHC or aldrin at planting time.

Sesame

In some areas, the sesame moth, *Antigastria catalaunalis* (Dup.), is the limiting factor in production. Insecticidal control has not been studied as other cash crops can be grown.

Beans

Seed treatment of seed beans with aldrin has proved useful against bean-fly, *Melanagromyza phaseoli* (Coq.), a slurry of aldrin powder with water giving better retention than the powder itself. " Rogor 40 " appeared promising as a control but is not available in powder form suitable for seed dressing.

Cotton

A very thorough investigation of the value of insecticidal control of cotton pests in the Eastern Province growing area has been carried out. It has been found that 1 lb. of DDT per acre applied eight times at weekly intervals, beginning when the average number of flared squares is one per plant, as a dust gives reasonably good control of American and spiny bollworms, *Heliothis armigera* (Hb.) and *Earias* spp., and economic increases in yield. Application as a spray gives better control and higher increases in yield. *Aphis gossypii* Glover can also cause heavy losses, particularly later in the growing season. Effective control can be achieved by adding 0·25 lb. of BHC per acre to each application as necessary. The addition of BHC increases the cost appreciably and the recommended application for peasant growers is 0·75 lb. DDT per acre in 10 gal. water applied weekly for two months. This is a compromise between the more efficient control achieved by the higher rate of 1 lb. and the amount a peasant farmer is prepared to spend on insecticides.

In a biological study carried out in 1958–59 it was found that American bollworm larvae were few in numbers in late September on pigeon pea and fiwi bean after a long dry season. A few small larvae were found in regenerated groundnuts soon after the first rains in late December. In January, large numbers were found on flowering weeds and groundnuts. This sudden build up suggests that diapausing pupae are of considerable importance in the carry over of the pest from one season to the next.

PASTURES AND HERBAGE CROPS

No detailed surveys have been carried out but locusts, grasshoppers and army worm, *Laphygma exempta* (Wlk.), occasionally cause very serious damage to grasses and fodder legumes. The latter appears to prefer star grass, *Cynodon dactylon*, to rhodes grass, *Chloris gayana*, whilst *Setaria* spp. are rarely consumed.

TREE CROPS

Cashew

With the spectacular increase in value of this crop during the last six years, from £554,000 to £1,562,000, its pest problems have been investigated. The two main pests are the Mirids, *Helopeltis schoutedeni* Reut. and *H. anacardii* Miller. Other pests of some importance are *Pseudotheraptus wayi* Brown, a curculionid borer, *Mecocorynus loripes* Ches., and *Selenothrips rubrocinctus* (Giard.).

Damage to seedlings by *Helopeltis* spp. can be severe, reducing its subsequent rate of growth and producing an untidy bush rather than a clean-trunked tree. Control by dieldrin and BHC is being studied.

The life history of *M. loripes* has been worked out.

Cocoa

There is renewed interest in cocoa. The chief pests found so far are *H. schoutedeni*, *H. anacardii*, *P. wayi*, causing severe damage to the fruit. *Planococcus citri* (Risso) causes severe distortion of the plant by damaging the growing point.

Coffee

The white coffee-borer, *Anthores leuconotus* Pasc., can be very satisfactorily controlled by spraying with 0·5 per cent. dieldrin emulsion twice yearly to the lower 18 in. of the main stems at a rate of 18 gal. per acre (540 trees). A suitable method for the peasant farmer at a much lower cost was devised. A band of the emulsion was applied with a brush on the main stem extending from 3 in. below soil level to 6 in. above soil level. Borers living above this level can be removed by hand.

The berry-borer, *Stephanoderes hampei* (Ferr.), causes considerable damage in the Lake Province. Spraying with dieldrin has been successful in a number of instances but re-infestation can occur rapidly unless the sprayed areas are isolated from unsprayed areas. The berry-moth, *Thliptoceras octoguttale* (Fldr.), has considerably increased in numbers over the past few years and instead of just " thinning " the crop it can cause very severe damage in many areas. General biological and insecticidal control studies are being carried out.

The leaf-miners, *Leucoptera meyricki* Ghesq. and *L. caffeina* Wshbn., may be the cause of much leaf-fall. A comprehensive study is in progress to estimate losses of crop due to leaf-miners and leaf rust under shaded and open conditions. A detailed biological study of the factors, biological and physical, determining population fluctuations is being carried out to assess the possibilities for biological control.

STORED PRODUCTS

Trials on two 120-ton parcels of high moisture maize in underground sealed pits were opened after 144 and 374 days. In both cases there was loss of palatability and viability and also a darkening in colour. Conditioning and admixture with a more palatable grain was necessary before consumption.

Hermetic sealing of bagged grain, stored in a normal warehouse, can be achieved by the use of a reasonably priced roofing felt. Maize has been kept in a good condition for at least two years.

VETERINARY

A territorial tick survey is in progress. Strains of *Boophilus* spp. resistant to BHC have been reported from several areas.

TSETSE SURVEY

Numerous surveys have been carried out in various parts of the Territory in connection with land settlement schemes and sleeping sickness. The Department of Tsetse Survey and Reclamation has been merged with the Veterinary Department.

TRINIDAD

1. REVIEW OF AGRICULTURAL ENTOMOLOGY

By G. Stell

Department of Agriculture

Coconuts

From studies still in progress on red-ring disease, *Aphelencoides cocophilus* (Cobb), it appears that the transmission of the nematodes occurs mainly through the soil where roots of adjacent palms are almost contiguous; the role of the palm weevil, *Rhyncophorus palmarum* (L.), in the spread of this disease is now held to be of less importance than was previously considered.

Outbreaks of the giant grasshopper, *Tropidacris dux* (Drury), occurred in the years 1954 and 1957 in the south-west of the Island where the preferred host plant *Quassia amara* is common. Experiments with dieldrin sprayed over about 80 acres gave good control.

Sugarcane

In certain areas nymphs of froghoppers, *Aeneolamia varia saccharina* (Dist.), have become resistant to chlorinated hydrocarbons, but good control has been achieved by organophosphorus insecticides. The lesser corn stalk borer or " jumping borer," *Elasmopalpus lignosellus* (Zell.) was reported for the first time in 1957 and caused widespread damage to the young shoots of ratoon canes, particularly where trash had been burnt. Isolated outbreaks of the Eumolpid, *Myochrous rhabdotus* Blake, occurred in 1954 and 1956. These beetles feed on the base of the growing leaf causing the leaf to fall and the actual damage is thus greatly in excess of that caused by the beetle itself.

Cacao

Steirastoma breve (Sulz.) has been much more active in the territory since the last review, and control measures have been more widely adopted. These consist of the provision of better shade and the application of lead arsenate sprays.

The fungus disease *Ceratostomella fimbriata* (Ell. & Hals), which was first recorded as a minor pod rot of cacao in 1936, was again noticed as a wilt disease of trees in 1958 and has since become much more widespread. At least six species of scolytid beetles and one Platypodid have been found in diseased trees and their possible rôle in the transmission of the fungus is being investigated.

Citrus

Promising results have been obtained with the organophosphorus insecticide Trithion, for the dual control of rust mite, *Phyllocoptruta oleivora* (Ashm.), and scale insects—mainly *Chrysomphalus ficus* Ashm. and *Lepidosaphes beckii* (Newm.)—by high and low volume methods of spraying. With the advent of the mist-blower, the colonial webbing spider, *Araneus socialis* (Holm.), which strangles the growth of trees, is now easily controlled by low volume spraying with BHC. Bagworm caterpillars, *Oiketicus kirbyi* Guild., which before 1958 had been uncommon, have caused serious local defoliation of citrus and many ornamental trees.

Bananas

The most serious pest of bananas is *Cosmopolites sordidus* (Germ.). The best preventive treatment has been shown to be either immersing suckers in a solution of aldrin or dusting the plant with aldrin, and spraying around the base of the plant with dieldrin at six-month intervals for plantains, and once a year for bananas.

Pasture and Herbage Crops

Pastures planted with Pangola grass, *Digitaria decumbens* Stent., have been found to be liable to severe attacks by froghoppers if the sward is not regularly grazed.

Vegetables

The serpentine leaf miner, *Liriomyza strigata* (Meig.), previously little known in Trinidad, has become increasingly common and is a serious pest of tomatoes. It has been successfully controlled with parathion.

Stored Products

The admixture of 0·5 per cent. lindane dust with seed paddy at the rate of four ounces per 100 lb. failed to give satisfactory control of storage pests beyond seven months, when *Rhizopertha dominica* (F.) and *Sitophilus sasakii* (Tak.) became apparent.

Plant Quarantine

In view of the outbreak in Florida of the Mediterranean fruitfly, *Ceratitis capitata* (Wied.), a survey was carried out in 1956 in Trinidad by the United States Department of Agriculture, with negative results.

General

Although not of economic importance it is of interest to note that the petroleum fly, *Psilopa petrolei* Coq., has been recently found in the Trinidad oilfields. A short account of this and of other Trinidad insects, whether or not of economic importance, may be found in " Insect Life in the Tropics " by T. W. Kirkpatrick. (Longmans, London).

2. BIOLOGICAL CONTROL INVESTIGATIONS CARRIED OUT ON BEHALF OF TRINIDAD DURING THE PAST FIVE YEARS

By F. D. Bennett

Commonwealth Institute of Biological Control

Although the Commonwealth Institute of Biological Control maintains an active station in Trinidad most of the projects at the station have been on behalf of other territories either elsewhere in the West Indies or further afield. This work has been summarized in the report of the Director of the Commonwealth Institute of Biological Control and by the countries for which the work was undertaken.

In Trinidad, a continuous study of *Diatraea* spp. in cane, their seasonal variation and the rate of parasitism was carried out for two consecutive years beginning in 1953. Parasites for trial against *Diatraea* were obtained from Mauritius and Mexico. From the former, *Apanteles flavipes* (Cam.) and *Xanthopimpla stemmator* Thnb. were liberated in small numbers only, since they could not be bred in the laboratory. A Mexican strain of *Paratheresia claripalpis* (Wulp), which differs in host preferences from the Trinidad strain, and *Zenillia palpalis* (Aldr.), a parasite known to attack *Castnia licoides* Boisd., and *Diatraea canella* Hmps., were obtained from Mexico. A technique for breeding *Zenillia* was worked out and for the first time enabled this species to be bred and released in large numbers. Although initial recoveries were made it has not become established. It is suspected that races also occur in this species and stocks from Venezuela or British Guiana, where it is known to breed on *Castnia*, would be better adapted to Trinidad conditions than was the Mexican stock.

Natural enemies of *Aeneolamia varia* (Dist.) were investigated in 1955–56 and the possibilities of mass-breeding the Syrphid *Salpingogaster nigra* Schin. considered. Field observations showed that the species built up quite rapidly in the field but later in the season populations were reduced by an Encyrtid parasite, *Aphidencyrtus* sp., which greatly curtailed its usefulness. With the assistance of the mycologist at the Imperial College of Tropical Agriculture a method of breeding the fungus *Metarrhizium anisopliae* Sorokin on a liquid medium was developed in 1957, but this work was stopped when the mycologist resigned. A Reduviid predator, *Castolus plagiaticollis* Stål., was introduced from Mexico, bred in the laboratory and liberated against *Aeneolamia*. Later observations have indicated that it was not likely to be a very efficient predator even if it did become established.

In 1959 *Elasmus zehntneri* Ferr., *Rhaconotus scirpophagae* Wlkn. and *Aprostocetus israeli* Mani, parasites of Indian sugar-cane borers, were received from India for trial on West Indian species of sugar-cane borers. Only *A. israeli*, a pupal parasite, could be reared successfully on *Diatraea* but because it also attacks Tachinid puparia no releases have been made.

Taxonomic studies on Encyrtid mealybug parasites were undertaken and cytological investigations of the Diaspine scale, *Pseudaulacaspis pentagona* (Targ.).

UGANDA

REVIEW OF AGRICULTURAL ENTOMOLOGY

By John Bowden

Senior Entomologist, Department of Agriculture

Many of the developments foreshadowed in the report submitted to the last Commonwealth Conference (Michelmore, 1954) have become realities in the past six years. The Entomological Section is stronger in both professional and senior technical staff than at any time in its history. This vastly improved position has enabled great advances in pest control in both the major cash crops of the country, cotton and coffee, as well as control of some of the main pests of food crops, *e.g.*, banana weevil and storage pests. The implementation of control techniques which satisfy immediate requirements and are likely to maintain adequate control for some time to come has also allowed greater attention not only to a variety of other pests but now permits more fundamental investigations such as the relation of pest attack to nutrient status of the plant, to climatic conditions, distributions within economic crops and wild host plants, etc., all of which are vitally necessary for the establishment of satisfactory long-term control.

The need to extend research findings to field control has presented manifold problems, and it is important to realise that each pest/crop association requires its own approach. One major factor that must be recognised is that a crop of considerable economic benefit to the country is not necessarily of similar benefit to the cultivator. For instance, cotton produces a large proportion of the Exchequer revenue of Uganda, but the average cultivator probably derives no more than Shs. 200 per acre per annum from his cotton crop, which has a heavy labour requirement that frequently interferes with operations on food crops. At this low cash return per acre, cotton naturally takes second or third place in poor seasons, when the main effort is directed to ensuring adequate food supplies. At the same time it is true that in large areas of Uganda the cotton crop may provide as much as two-thirds of the annual cash income of the cultivator. This emphasises a fact too often overlooked, that the average peasant in far too many cases simply does not have the money to purchase pest control requirements, and as often as not this is the major stumbling block to successful extension.

On the other hand, a crop such as *arabica* coffee is profitable even at relatively low yields per acre, and can comfortably carry the costs of pest control. Given this situation it is possible to consider techniques and equipment far outside the scope of that of the cotton cultivator. Further, a crop such as *arabica* coffee has a limited ecological zone in Uganda, and there is a marked tendency for aggregation of individual plots into a series of relatively dense areas of coffee. In its turn this introduces the possibility of techniques based upon mass spraying which, when possible, is more efficient than the efforts of the majority of individuals.

Factors such as these have determined the approach to extension of research findings. In cotton, control is organised through the individual peasant, using simple hand equipment and receiving financial assistance. In *arabica* coffee, control is by means of organised teams using motorised knapsack mist-blowers the cost being defrayed (after one or two free sprayings as a propaganda measure) by the grower or by growers' co-operatives. In both cases results have been gratifying, and have not only led to an increasing insecticide consciousness among some of the farming community, a development which is to be welcomed provided one also realises the dangers involved, but also to a more general willingness to heed advice given by district agricultural staff. All too frequently agronomic extension work is a profitless pursuit, but the introduction of pest control, particularly when as with *arabica* coffee the results are spectacular, provides the breakthrough necessary to demonstrate that there is something of value in the advice given by Departments of Agriculture.

Pests of Cotton

Apart from the introduction of spraying on a large scale in Northern and Eastern Uganda, the most important development in cotton entomology has been a reassessment of the causes of crop loss. It has previously been held that *Lygus vosseleri* Popp. was the major pest throughout Uganda, the response to insecticidal treatment varying between the moister Lake Victoria zone and the drier inland areas of Northern and Eastern Provinces. The difference in response is due to the more favourable rainfall régime around the lake, which enables the cotton plant to set a top crop compensating for the early bottom crop lost to insect attack, whereas in inland areas the shorter rainy season does not allow sufficiently prolonged growth for compensation to occur.

There are two characteristic symptoms of *Lygus* damage, one is the " tattering " of leaves, caused by the rupture of the leaf around feeding sites, the other an elongation of the main stem with a varying degree of suppression of the monopodia and sympodia. These symptoms become progressively more apparent in June–August planted cotton in Northern and Eastern Uganda, from about 8–10 weeks from planting, and their appearance generally coincides with the maturation of the main cereal crops, sorghum and finger millet, which are known to harbour *Lygus*, and from whence the *Lygus* migrate to the cotton crop. However, agronomic studies showed that in the east and north the optimum time of planting was much earlier than the standard planting period of mid-June to August, and by superimposing sprays on cotton of various planting dates, it can be shown that the yield increment from spraying early (May) cotton is greater than that from spraying later (June and July) cotton. Data from an extensive series of district plots have been published (Bowden and Ingram, 1958a), and several more formal experiments confirm these findings. The spray schedule comprised four applications at ten-day intervals of 1 lb. DDT per acre per application, beginning eight weeks from emergence. Now with cotton planted in early May the spraying is complete before the expected migration of *Lygus* into the crop. Therefore, if *Lygus* is indeed the culprit, one would not expect much, if any, response from spraying which missed the main pest peak. Thus, it was apparent that some other pest was being controlled.

It is thought that the major pest is, in fact, spiny bollworm—*Earias biplaga* Wlk. and *E. insulana* (Boisd.), acting not as bollworms, but as shed-worms and tip-borers (Bowden and Ingram, 1958b). It can be shown in the laboratory that first-instar *Earias* larvae will cause the development of leaf-tattering, which is therefore not a symptom characteristic of *Lygus*, and also that even one *Earias* larva will cause such severe damage to main and lateral growing points as to result in plants barely recognisable as cotton.

Apart from damage to fruiting points and growing points, *Earias* larvae cause a high level of flower damage (Bowden and Ingram, 1958b), which can be shown to be controlled by DDT and is directly correlated with subsequent yield increases.

Further, analyses of shedding data, which are still in progress but which will be published in the near future, show consistently negative regression coefficients between bollworm sheds (and it is a matter of common observation that in northern and eastern areas *Earias* is by far the commonest bollworm) and subsequent yield. On the other hand, leaf-tattering indices and especially sheds due to bug puncturing show either a slight negative regression or a marked positive regression. Space does not permit fuller exposition of the *Earias* theory, but in brief it is that *Earias*, by its activity at an early stage of crop growth causes the loss of both structure and the earliest fruiting points, for which the plant cannot compensate. *Lygus* (or more correctly Mirid) damage is marginal, and is dependent upon the seasonal ability of the crop to produce a late top-crop. A large proportion of sheds due to mirid damage would probably have been lost in any case, the number of these sheds having any relation to yield being dependent not only upon the overall ability of the plant to carry to maturity a given number of bolls, but also upon the amount of bottom crop carried. It can be shown that there is a strong negative correlation between bottom crop and top crop. Hence any loss of bottom (early) crop due to *Earias* activity is compensated for by top (late) crop. Thus the effect of mirid, including *Lygus*, attack is secondary to that of *Earias* which determines the level of the bottom, or the economic, crop.

Other experiments have shown that sprays commencing at five or eight weeks from emergence are more consistently effective than sprays commencing at ten weeks, the effectiveness of the latter depending upon the rainfall late in the growing season, favourable rains producing a response equal to that of the early spray starts. It has also been shown that four sprays are more effective than either three or two sprays covering approximately the same period. The following table illustrates this (all sprays 1 lb. DDT per acre per application):

Treatment	*Yield lb./acre seed cotton*
4 × 10 days	1351
3 × 15 days	1208
2 × 20 days	1186
0	797

The difference in this experiment of 143 lb. seed cotton between four sprays and three sprays more than offsets the additional (approx. 15/-) cost of insecticide.

The standard recommendation for spraying peasant cotton is thus four sprays at 10-day intervals of 1 lb. DDT per acre per application, beginning at eight weeks from emergence of the crop. Application is done by the peasant himself, using a simple double-acting syringe pump, the basic design for which was evolved in Uganda. Using this pump, 8–12 gallons wash per acre is well within the capabilities of the cultivator. In 1959, in the second year of an extension spraying campaign, 12,000–14,000 acres of peasant cotton were sprayed.

As was pointed out earlier, cotton is barely economic at peasant level, so that even though the increases in yield from spraying are highly economic provided spraying is limited to early-planted cotton (which, in any case, has an inherently higher yield) a major obstacle to peasant spraying was the inability of the cultivator to find the money necessary to purchase pump and insecticide. In the first two years of the campaign to spray cotton, loans, administered by African Local Governments assisted by Departmental staff, were made available. It was apparent in 1959 that this system was extremely unwieldy and diverted a disproportionate amount of Departmental time and effort to certifying and collecting loans. For 1960, the Government has accepted the principle of a subsidy for insecticide, which has reduced the price to a level considered well within the means of the average peasant farmer.

Various aspects of the biology of *Earias* spp. are under investigation, particularly more detailed studies of its relation to crop loss, and its incidence in wild hosts, of which there are numerous recorded species in the Malvaceae and related families. While the theory that *Earias* is responsible for observed crop losses in inland areas obviously does not alter the fact that responses to insecticide are different in the lake area, it is now necessary to re-investigate insecticidal treatment of cotton around the lake in the light of this revised interpretation of the causes of loss elsewhere.

An investigation of cotton-seed bugs, *Oxycarenus* spp. (Odhiambo, 1957), showed that in Uganda *Oxycarenus* is a minor pest. Three species are involved, *O. dudgeoni* Dist., *O. fieberi* Stål. and *O. rufiventris* Germ. Although these species are polyphagous, primarily among Malvaceae, there are differential host preferences, *O. dudgeoni* being commoner on cotton, *O. fieberi* on *Sida* spp. and *O. rufiventris* on *Hibiscus cannabinus*. Cotton is infested by migration of adults from *Sida* and *Hibiscus* plants near and within cotton fields. Damage is primarily a lowering of germinability of seed, this effect being apparently independent of the number of bugs per boll. Lint staining, which has been considered in other countries to be important, was shown to be negligible in Uganda conditions. The usual procedures of sunning picked cotton, combined with the storage periods normal before ginning, are sufficient to remove most, if not all, bugs from seed cotton.

Close watch has been kept on all spraying experiments for development of mite attack. Outbreaks of tea mite, *Hemitarsonemus latus* (Banks), have afforded opportunity of an assessment of the importance of this pest. It is concluded that what little damage it may cause is entirely outweighed by the damage inflicted by the bollworm-Mirid complex, and it is, moreover, controlled by DDT. Red spider mite, of the *Tetranychus telarius* complex is more prevalent than *H. latus*, and is frequently asserted to be more serious on sprayed cotton. This is not, at present, the case but red spider attack does appear to be related to senescence in many cases, which leads to reports of attacks on sprayed cotton, since this matures much earlier than unsprayed and attracts more critical attention. However, it is a matter of simple observation that where sprayed cotton is attacked, any unsprayed comparison will also show attack as the latter matures. Nevertheless, the present spray recommendation is finely balanced in relation to red spider mite, and any increase in the amount of insecticide applied and/or length of spray cover could well result in more generally severe attacks.

Pests of Coffee

The major effort in coffee entomology has been to find an adequate control of *Antestiopsis lineaticollis* Stål, the most widespread and most serious pest of *arabica* coffee. Cultivation of *arabica* coffee is largely confined to the higher areas of Mount Elgon in the east, the Ruwenzori foothills and the hill country of Ankole and Kigezi in the west. In all these areas the ravages of *Antestiopsis* had reduced the standard of the trees to a parlous state, large areas having gone out of bearing and in Ankole, in particular, *arabica* was being replaced by *robusta* coffee which is not affected by *Antestiopsis*. The discovery of a control that could be applied on a large scale in peasant coffee was, therefore, a matter of some urgency.

Work by colleagues in Kenya had shown that malathion provided effective control, and neither did this insecticide pose any problems of residual activity. It has been learnt from bitter experience that applications of persistent insecticides, such as DDT, almost inevitably result in outbreaks of insects normally relatively minor pests in Uganda, *e.g.* leaf miner. The advent of malathion was of inestimable value in coffee entomology, perhaps more so in Uganda where insecticidal treatment of coffee, except for one disastrous effort with DDT, had been confined to pyrethrum, and consequently no leaf miner problem existed.

Field trials showed that two pints per acre of a 50 per cent. concentrate of malathion reduced *Antestiopsis* populations by 90+ per cent.; even one pint per acre was adequate provided the trees were pruned, but the general standard of pruning leaves much to be desired, and the higher dosage has been recommended for general practice. The next problem was to find a technique suitable for large-scale spraying, and after extensive field-work a method has been evolved based upon teams of mist-blowers. Even in areas of scattered coffee, which have necessitated the establishment of fully self-contained mobile units the team-spraying technique has proved highly effective, and results have been spectacular. It is extremely difficult to persuade the African peasant to allow exact recording of yield increases, usually because he suspects it to be a nefarious Government plot to extract more money from him. It is, however, possible to gauge results by general revenue increases from the coffee crop in some areas. In one of these, 200 acres of sprayed *arabica* brought an increased income to the farmers of £27,000, plus revenue from export taxes of £5,000, at a cost of Shs. 51 per acre. Not only has spraying increased the crop from standing trees, it has also arrested the move towards *robusta*.

Extensive trials are still in progress with varying rates of malathion and frequencies of spraying. Concurrently, trials are being conducted on improved techniques of spraying, including comparative tests of several mist-blowers.

It was early apparent that the standard method of assessing *Antestiopsis* populations was unreliable. A plot of data obtained by the usual two-tree test spray revealed a completely non-random distribution and could not, therefore, be used in either experimental or survey work. Since it is possible to consider a simple binomial distribution of trees with or without *Antestiopsis*, a sampling technique was worked out based upon a presence-absence record, a record also being kept of the numbers of insects on infested trees. When these data were plotted it was found that a marked skew distribution results, the amount of skew seeming to depend upon the average population level. Further work has shown that a contagious distribution curve provides an admirable fit to observed data, and a field-sampling technique is being developed based upon this distribution; the sample frequency is determined by the level of *Antestiopsis* populations which it is considered warrant spraying.

Exact data on the relation of population level to crop loss are nowhere available, the only figures extant being that 1–2 *Antestiopsis* per tree cause economic loss. Since these figures were obtained by the method since shown to be inexact, it is necessary to reinvestigate population levels of *Antestiopsis* and an extensive programme of research is now in hand.

Coffee lacebug, *Habrochila ghesquierei* Schout., has become increasingly important, especially in the Mount Elgon area (Bugisu district), where about 1,000 acres are affected. Extensive investigations into the bionomics of the insect have been undertaken, with most interesting results. It has been found that active racial differentiation is in progress. Colonies of *H. ghesquierei* from Bugisu district, from Buganda (Kawanda Research Station) and from Ruwenzori have been cultured side by side in the laboratory, and striking differences have been found between these races, particularly in the structure of the egg. There is also a small but significant difference in length of ovipositor between the Buganda and Bugisu races, apparently correlated with a difference in oviposition habits. The Buganda strain shows a marked preference for ovipositing in the leaf, whereas Bugisu females seem to prefer the growing point as an oviposition site. There is a general tendency for the immature stages of the Buganda strain to develop faster than the Bugisu strain.

A remarkable feature of the field biology of *H. ghesquierei* is the marked cyclic population fluctuations. The cause of this periodicity is not known, but there are indications that it may be connected with tree physiology. There are numerous observations which are difficult of explanation on any other basis, *e.g.*, one group of trees is severely infested while an adjacent group is unaffected; the highest populations appear to coincide with the flowering cycle of the tree. It is intended to study the carbohydrate/nitrogen status of the coffee tree in relation to crop development and lacebug biology.

Control of *H. ghesquierei* is not at present satisfactory. Recommendations from work in Kenya of two malathion sprays at a 21-day interval have given only moderate control. It is thought that this is due to differences in the length of the incubation period. In the Bugisu race this averages about twenty days, but a good proportion of eggs hatch between twenty-one and twenty-four days, the resultant nymphs being unaffected by the insecticide. Trials are in progress testing different frequencies and also other insecticides and spraying techniques.

The investigation of *H. ghesquierei* has also clarified the status of *H. placida* Horv. The account given by Hargreaves in Tothill's " Agriculture in Uganda " 1940, does not refer to *H. placida*, but to a form of *H. ghesquierei*, the figures of both egg and adult being of the latter species. *H. placida* is restricted to *robusta* coffee, and is very different in its bionomics, structure of the egg and adult. *H. placida* also exhibits marked cyclic fluctuations in the field, which are even less explicable than those of *H. ghesquierei* in view of the tremendous variability of the length of development of all stages of *H. placida*.

Coffee berry borer, *Stephanoderes hampei* (Ferr.), is still ubiquitous in *arabica* and *robusta* coffees, and no real progress in control has been made since 1954. The main difficulty is the absence of an adequate sampling method, which depends upon an accurate knowledge of the distribution of attack within and between trees. This problem is being tackled, and has involved the recording for every single berry position within the tree and presence or absence of borer, on about twenty well-grown trees. These data are now being marshalled for analysis. Prospects for insecticidal control are not good, particularly in view of the dangers attendant on the use of persistent insecticides. The standard recommendation for control is still that of regular picking, and destruction or disposal of " mbuni." Judging from Departmental stations practising these recommendations, berry borer incidence can be reduced to a low level.

Coffee root mealy bug, *Pseudococcus latipes* De Lotto, has become more serious, particularly in Buganda and Bugisu. A 2·5 per cent. lindane or aldrin dust provides excellent control, the latter insecticide being preferred for *arabica* because of a lesser risk of taint.

Grain Storage Entomology

In common with all other tropical African territories, considerable, and for the most part avoidable, losses of stored grains and pulses occur annually in all types of storage.

The largest individual storage project in Uganda, the so-called grain conditioning plant at Jinja, has been taken over by a commercial organisation, but amicable co-operation continues. Its bulk storage facilities offer admirable opportunities for various disinfestation techniques. It has been shown (Davies, 1958) that " Phostoxin "—an aluminium phosphide formulation—achieves excellent control of heavy infestations, but that at the dosage recommended by the manufacturers some survivals of both *Tribolium castaneum* (Hbst.) and *Ephestia cautella* (Wlk.) can be expected, whereas *Sitophilus oryzae* (L.), the pre-adult stages of which have proved elsewhere to be rather resistant to this fumigant, is completely controlled.

In experiments on small-scale storage, suitable for individual farmers or small co-operative groups, it has been found that maize, if it is to be kept for more than four to five months in native cribs, etc., must be treated with insecticide. Provided reasonable care is taken to select cobs with good, intact sheaths, maize can be stored on the cob for about five months without serious damage, but thereafter the damage rate climbs rapidly. Dusting the cob with lindane, at the rate of nine oz. of 0·5 per cent. dust per 200 cu. ft. of cobs, will provide adequate protection for several months, even in the moist areas of Buganda, where it has been suggested that normal crib storage would be impossible because of prevailing high humidities. For shelled maize, admixture of eight oz. of 0·5 per cent. lindane to 200 lb. grain also provides satisfactory control for prolonged periods (Davies *l.c.*).

Concurrent with these studies of maize stored more or less according to traditional practice, investigations have proceeded with maize stored in small (twenty ton) capacity silos of both aluminium and plywood. Aluminium silos have proved satisfactory (Davies, 1960) provided that due care is taken to construct an adequate and waterproof base. Plywood silos have the advantage of cheapness, but an experiment in progress at the time of writing indicates that waterproofing and structure in general are inferior to the aluminium silos.

An interesting subsidiary investigation has been made into the palatability of maize stored for prolonged periods (Coaker and Davies, 1958). It was found that presence or absence of insect damage had little effect upon palatability ratings given by a panel of African tasters. Tests showed that a distinction could be made between old and new maize, both lots being free of insect damage or other effects of poor conditioning and storage. However, if maize was presented as roller-milled flour the distinction between old and new was less readily made than with hammer-milled maize. This is probably because in hammer-milling no part of the grain is extracted from the final product which, therefore, has a higher acidity due to the presence of the germ which contains a large proportion of fats and oils, hydrolysis of these over prolonged storage giving rise to fatty acids. Thus, not only must attention be given to adequate storage conditions, but the maize must also be sold to the consumer in a palatable form.

In regard to beans, which are invariably attacked by Bruchids, considerable saving has been demonstrated when beans are dusted with 0·04 per cent. γ BHC at eight oz. per 200 lb. (Davies, 1959). This is essential for all beans kept for more than three months, and the cost of the treatment (60 ct. (EA) per 200 lb. bag) is such that it is well worth while treating peasant holdings as well as larger stocks held by buyers.

Cereal Pests

A country-wide survey of the Lepidopterous stalk borers that occur in Uganda was carried out in 1954–56, with experiments on their control continuing until 1958 (Ingram, 1958; 1960). A complex of Noctuid and Pyralid borers was revealed, the more important being *Busseola fusca* (Fuller), *Sesamia calamistis* Hmps., both Noctuidae and *Chilo zonellus* (Swinh.), Pyralidae.

B. fusca is widely distributed, but most abundant in areas of intensive cultivation, attacking all the main cereal crops, sorghum, maize, sugar cane, finger millet (*Eleusine coracana*) and bulrush millet (*Pennisetum typhoideum*) but not rice. *B. fusca*, although able to breed in many wild hosts, does not occur in large numbers unless conditions suitable for the larval resting stage occur. The wild grasses are severely burnt annually, probably killing large numbers of larvae, so that only those resting in crop trash or stubble fields can survive. Crops grown out of season frequently carry heavy populations of *B. fusca*.

S. calamistis is widely distributed, but does not occur in areas with a severe dry season, there being no resting stage to carry over. It is not very common and heavy attacks have not been recorded, but it is one of the only two species infesting rice.

C. zonellus appears to be a recent introduction, probably since 1953. Already it is the commonest borer in the country, although less widespread than *B. fusca*. It seems that its present distribution is correlated with altitude below 4,000 ft. in Western Uganda and below 5,000 ft. in the east and north. The difference between the two areas is probably due to temperature, comparison of the high western area showing it to be about 10°F. cooler, the whole year round, than the lower northern area. Neither does *C. zonellus* occur in districts with extreme dry season conditions, probably because of the absence of wild hosts, or wild hosts in a suitable condition, no larval resting stage being known. At the moment *C. zonellus* is rarely of economic importance, but if it is a recent introduction it may well further adapt itself to local conditions and become a more important pest.

Large acreages of sorghum are grown particularly in Northern and Eastern Uganda, and the crop is always attacked to some extent by borers. While the surveys revealed little apparent economic damage, experiments on borer control were nevertheless conducted, all three borers listed above being present in the experimental sorghum crops. Treatments consisted of varying numbers of applications and rates of DDT dust and miscible liquid and blanket treatments of dieldrin throughout the crop growth. It was not possible to show significant increases in yield even with a large reduction in the numbers of borers present.

It is thought that the main reason for the apparent lack of response to borer control is that sorghum tillers heavily with an early borer attack and it is possible to harvest more heads in a badly attacked plot. In a second-rains trial in 1956, there were more heads in the control plots than in the treated, and although they weighed less individually, no significant yield difference resulted. Quite apart from lack of response, the cheapest of the higher yielding treatments—a DDT dust—cost Shs. 100 per acre, excluding labour, a level that a peasant grain crop such as sorghum would be incapable of supporting.

Sorghum is also afflicted in its early growth by a complex of shoot-flies, including *Atherigona indica infuscata* Emd. (Muscidae) and *Scoliophthalmus micantipennis* Duda (Chloropidae). None of the treatments tested against stem-borers appeared to control shoot-fly attack, neither did repeated applications of different rates of malathion or Rogor, both of these insecticides causing various degrees of scorch. A satisfactory assessment of the damage caused by shoot-fly is not at present possible. One can expect some compensation for damage by increased tillering, as occurs in stem-borer attack, but to what extent this is in turn offset by over-tillering in heavy attacks is not known.

Pests of Banana

Bananas form the staple diet of large numbers of people in Uganda, and, as elsewhere, banana weevil is prevalent. It had been assumed that one species *Cosmopolites sordidus* (Germ.) was involved, but it is now known that two, and possibly four, species of weevil will attack living banana in Uganda (Whalley, 1957; 1958). *C. sordidus* is present all over Uganda except for some western areas, and is undoubtedly the major pest. Three species of *Temnoschoita* have also been reared; *T. nigroplagiata* (Qued.) is distributed throughout Uganda, but is particularly common in those areas in which *C. sordidus* is absent or rare; *T. basipennis* Duviv. is local and uncommon, while *T. erudita* Duviv. has been recorded as adults from Western Province. An account of the larva of *T. nigroplagiata* and its distinction from *C. sordidus* has been published (Whalley, 1957).

A good degree of control has been obtained using a dieldrin 0·5 per cent. dust. This dust is applied by a simple shaker duster to the stools around the base of the pseudostems. " Poison traps " are also prepared by splitting pieces of pseudostem, dusting the cut surfaces and laying the dusted surface downward. These traps give a high kill and quickly clear a plantation. The rate of application is 35 lb. to 112 lb. dust per acre, depending upon stool density; two or three initial applications are recommended at four- to six-month intervals, but thereafter one dusting a year appears to be enough to deal with reinfestation.

However, in spite of the simplicity of the method, and its relative cheapness (Shs. 17 to Shs. 55 per acre, depending upon stool density and number of traps laid) the peasant farmer has been slow to adopt control. There are probably several reasons for this, including the fact that there is no real shortage of bananas, that, in Uganda at least, damage is probably less severe than at first sight appears, with probably less crop loss than is assumed to occur, and because no spectacular responses are seen; this visual proof of the effectiveness of an insecticide is of great importance in extension campaigns among a relatively unsophisticated farming community.

Other Activities

Phytosanitary matters occupy an increasing amount of time, and an officer has been appointed to deal with the routine involved, and also to carry out inspections of storage premises, both as part of a drive to introduce improved storage and as routine inspections to guard against the introduction of *Trogoderma granarium* Everts, outbreaks of which have been found in neighbouring Tanganyika.

The introduction of regular light trapping is beginning to produce valuable information on seasonal incidence of several pests, and is also augmenting the insect collection at a rate outstripping storage facilities. The extensive collections now available have been the basis for revisionary and descriptive work on East African Miridae, and material has been gathered for work on the Noctuidae and Pyralidae associated with Gramineae.

Locusts have fortunately not been in evidence other than occasional small swarms and individuals. Neither has the Kagera dwarf locust, *Faureia milanjica* (Karsch), been active.

Surveys have been conducted on various crops in which interest has been shown as possible additional cash crops. A list of those found attacking castor (*Ricinus communis*) comprises over 20 species and, as elsewhere in East Africa, insects appear to be a primary cause of poor crop setting.

Cacao, which was originally introduced fifty-odd years ago, is again a source of interest and would appear to have good prospects in several areas of Uganda. Already three potentially severe pests are known: a scale, as yet unidentified, which can be found in some numbers on the petiole of the pod; *Earias* spp., the larvae of which both bore into growing points and ringbark seedlings; and *Helopeltis* sp., which at present confines its activities to pods, but, if it is the same species, was reputed to have been one of the main causes in the decline of cacao cultivation thirty years ago.

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UNION OF SOUTH AFRICA

REVIEW OF WORK

By J. W. C. Geyer

ORGANISATION

During the period under review the organisation of entomological work as affecting Agriculture and Forestry has been falling gradually into the pattern of decentralisation initiated in 1949. Under this system the six Agricultural regions and three Speciality Institutions have been gradually taking over in practice their appointed functions under which each region deals with all problems in agricultural entomology within its area with the exception of Forest Pests. Each Speciality Institution on the other hand deals with the pests of the Speciality branch which it represents. Whilst these Institutions have no special territory each is centred in the heart of the main production area involved. It essays to cater for the main needs of the industry as experienced by the headquarters area, the results of research being available to the whole country; aberrations arising from variation in ecological conditions are assessed and catered for, thus far mainly in theory, according to the demands of the situation, the main idea being that of substations where necessary and feasible.

The National Division's function is essentially co-ordination work through the control of projects. It retains, however, also certain functions which are best suited to centralised attention, such as taxonomy and identification work, insecticide research and control, stored products problems, the guidance of biological control work, Forest Insect problems—the latter not being provided for under the Department of Forestry—and plant quarantine issues not regionally provided for.

In addition, the National Division takes care of certain problems involving state campaigns, *i.e.*, Migratory Locusts and Granivorous Birds—handled locally by entomological staff—and gives exploratory attention to other problems in Agricultural Zoology.

In the four Universities with Agricultural Faculties the teaching staff engage in research as well as teaching; in the Regions individual workers sometimes attend to problems on a variety of crops and the same problem sometimes receives attention in several Regions.

Staffing—Divisions

National Division of Entomology (including Locusts). 1 Chief, 2 Assistant Chiefs, 4 Chief Professional Officers, 8 Senior Professional Officers, 14 Professional Officers and 21 Assistant Professional Officers.

National Division of Horticulture. 1 Senior Professional Officer, 1 Professional Officer and 1 Assistant Professional Officer.

National Division of Veterinary Services. 1 Senior Professional Officer, 1 Professional Officer and 2 Assistant Professional Officers.

National Division of Plant Control and Quarantine. 1 Chief, 1 Assistant Chief, 1 Chief Professional Officer, 1 Professional Officer and 2 Assistant Professional Officers.

Staffing—Regions

There are six Regions—Highveld, Karroo, Natal, Orange Free State, Transvaal and Winterrainfall—each with from 3 to 5 Professional Officers.

Staffing—Speciality Institutions

The Western Province Fruit Research Station has 1 Director and 5 Professional Officers, the Subtropical Fruit Research Station (Nelspruit) with 5 Professional Officers and the Tobacco Research Station (Kroondal) with 2 Professional Officers.

Staffing—Faculties

The Universities of Stellenbosch, Natal, Pretoria and the Orange Free State each have a Professor and 2 to 4 Lecturers.

INSECTS AFFECTING FIELD CROPS

Maize Stalk Borer—*Busseola fusca* (Fuller)

For the control of *Busseola fusca* the use of insecticides such as DDT applied to the funnel remains the basic recommendation. Although manual application to individual plants gives the best results the labour involved presents a real practical problem. In consequence efforts in recent years have been directed at means of efficient mechanical application. This has resulted in commercially successful aerial and tractor applications of DDT and endrin emulsions as cover sprays and DDT and Dipterex in granular form.

Lesser Maize Stalk Borer—*Sesamia calamistis* Hmps.

A study of the life and seasonal history of *S. calamistis* has been completed. In control tests endrin and WL1650 have given very promising results both being applied at the rate of 0·5 to 1 lb. per morgen.

Cutworms—*Agrotis segetum* (Schiff.)

For the control of *A. segetum*, soil treatment with insecticides has been disappointing but dieldrin, aldrin and Dipterex have been proved to be highly effective as the toxic agents in maize meal and bran baits, and they are replacing sodium fluosilicate that was previously used for this purpose.

Sorghum Midge—*Contarinia sorghicola* (Coq.)

C. sorghicola is a very recent discovery in the Union. Biological observations have shown that its main injury is to late planted sorghum. In consequence the main recommendation for its control is evasion by early planting.

Sorghum Aphis—*Longiunguis sacchari* (Zhnt.)

L. sacchari is, as a result of recent tests, being successfully controlled with aerial and tractor spray applications of various insecticides, including Metasystox. Under very dry conditions the physiological condition of the crop occasionally interferes with the satisfactory absorption of systemic insecticides.

American Bollworm—*Heliothis armigera* (Hb.)

H. armigera as a pest in sorghum seedheads has been effectively controlled by aerial applications of DDT and endrin and WL1650 in most cases. Varieties in which the head is of a closely packed formation, however, present some difficulty.

Peanut Aphis—*Aphis craccivora* Koch. (*leguminosae*, Theo.)

A. leguminosae as a vector of peanut rosette remains a serious problem. Under Union conditions thimet seed treatment has failed to give economically enduring protection; OMPA as a systemic moves too rapidly into the underground portions of the plants (seed-pods) and standard systemics do not persist long enough to render them economically feasible. The main control recommendation remains early planting, the maintenance of vigorous plant growth and the discouragement of volunteer peanut plants early in the season.

Potato Aphids—*Myzus persicae* (Sulz.) **and** *Macrosiphum euphorbiae* Thos. (*solanifolii* (Ashm.))

M. persicae and *M. euphorbiae* as vectors of virus elements responsible for potato seed degeneration have received intensive attention. Potential seed production areas selected on a basis of probably light vector incidence and movement, dictated particularly by unfavourably high temperatures are being studied. One such promising area when first selected has broken down under the accumulation of alternate hostplants. The alternative of insecticide depression of vectors under conditions of high vector incidence and movement, has been carefully tested, proving that it is at least possible to reduce leafroll spread within the field very considerably by the judicious application of Metasystox, thus eliminating the unwinged vectors. In order to arrive at the actual implication of these two vectors it was necessary to undertake faunistic and ecological studies which pointed to these two species as the most important but not the only local ones. The faunistic study uncovered much new information about the aphid fauna in general and is the subject of a paper to be published shortly. Two species were shown to complete the holocycle.

In addition careful inquiry was instituted into the basic desiderata of a good seed potato area under South African conditions. The conclusion was that climatic factors alone—temperature, air movement, humidity—supplied only part of the requirements and that ecological conditions, particularly the relative availability of alternate host plants are of cardinal additional importance.

Potato Tubermoth—*Gnorimoschema operculella* (Zell.)

G. operculella in the potato field is being controlled essentially by spraying with DDT emulsion and by judicious ridging. In the absence of storage conditions permitting the exclusion of moths from the harvested crop and of fumigation to eliminate initial infestation, crops often have to be stored in the open or in airily built sheds and storehouses. Under these conditions DDT dust has been successfully used to combat the development of serious infestations.

Wheat Aphis—*Toxoptera* (*Schizaphis*) *graminum* (Rond.)

S. graminum appears sporadically as a major pest of dryland wheat during the winter months owing apparently to a combination of lack of plant vigour and a breakdown of normal natural control as a result of abnormally high winter temperatures. Under these conditions satisfactory control was obtained through aerial and tractor-sprayer application of systemics—Metasystox, Metaisosystox, Phosdrin, Rogor 40 and Ekatin. It proved feasible in practice to employ remarkably low dosages, thereby reducing the cost and diminishing the hazard of eliminating aphid parasites and predators. These, however, still suffered very appreciably. The parasite *Aphelinus nigritus* How., has been introduced from Oklahoma in the hope of thereby strengthening the local parasite/predator complex in its weakest spot, *i.e.*, the absence of a parasite which can flourish under somewhat the same low temperatures as the host.

Castor Oil Mirid—*Eurystylus capensis* (Dist.)

E. capensis has become a noted sporadic pest as a destroyer of castor oil seed at setting time. Various insecticides, *e.g.*, DDT, endrin, WL1650 have given very good mortalities but reinfestation tends to build up at a rapid rate thereby rendering overall control costly.

Castor Oil Midge—*Asphondylia ricini* Mani

A. ricini does similar damage to that caused by *Eurystylus*. To date no satisfactory control has been evolved. Early planting is recommended.

Castor Oil Semilooper—*Achaea catella* Gn.

A. catella caterpillars cause severe and repeated defoliations of castor oil plants every season. They have been readily controlled by aerial and ground (tractor) spraying using DDT, endrin and toxaphene but repeated attacks in the same season render overall control relatively expensive.

Tobacco Slug—*Lema bilineata* (Germ.)

L. bilineata on tobacco is still being controlled by DDT sprays or dusts directed essentially at seedbeds and other early season hosts. It seldom attains serious proportions in the field.

Eelworm—*Meloidogyne* spp.

Meloidogyne spp. constitute major pests of tobacco. In the Union, research aimed at their control is handled by nematological personnel.

Other Insects

Other insects affecting field crops are ground weevils, *Protostrophus* spp.; wheat sandworm, *Eremnus cepealis* Mshl.; wheat bug, *Blissus* (*Ischnodemus*) *diplopterus* Dist. and the lesser armyworm, *Spodoptera* (*Laphygma*) *exigua* (Hb.).

PRINCIPAL PESTS OF PASTURE AND FORAGE CROPS

Armyworm—*Spodoptera* (formerly *Laphygma*) *exempta* (Wlk.)

S. exempta, apart from its damage to summer cereals, is a major though sporadic pest of gramineous pastures and forage crops. Over the period under review, tests with modern insecticides have rendered great advances in control measures. Amongst the safer insecticides giving excellent results are DDT, endrin, malathion, Dipterex and Sevin.

Mechanisation through the use of tractor sprayers and aircraft has contributed enormously to rapid and concerted control activities, so that it is largely feasible to save cereal and forage crops. As yet, however, the value of natural pasture renders insecticidal control relatively uneconomical. Pasture management coupled with the judicious use of insecticide offers a certain degree of relief. The actual origin of seasonal outbreaks, however, remains unsolved thereby excluding the possibility of preventive action.

Lucerne Caterpillar—*Colias electo* (L.)

C. electo remains a persistent pest of lucerne. Although DDT sprays offer a very effective means of control their use is officially discouraged. Recent work has led to the recommendation of malathion and Sevin dusts as satisfactory control agencies.

Karroo Caterpillar—*Loxostege frustalis* (Zell.)

L. frustalis is a serious sporadic destroyer of shrub elements, mainly *Pentzia incana*, of Karroo grazing. After attempts to use parasites of *L. sticticalis* (L.) on this insect had failed completely, attention was directed towards a purely ecological approach, insecticides being virtually out of the question because of the low value per unit area of the grazing involved. It has been noted that the damage caused by *Loxostege* is most intensive on grassless stands—the grass having been eliminated by intentional overgrazing—and that a fair intermixing of well-grown grass with the shrub elements tends to dissipate the oviposition of the moths thereby inducing a much lighter infestation of the shrub. Recent advances in pasture management have shown that, in many ecological situations, it is readily possible to induce the regeneration of the grass element to the overall improvement of the grazing value. This fact has opened a line of control of apparent promise against the insect and experiments are under way to test this theory.

Harvester Termites—*Hodotermes mossambicus* (Hagen) **and** *Microhodotermes viator* (Latr.)

H. mossambicus is a serious pest of grazing and small stemmed gramineous crops in the Union. Years of work have culminated in a comprehensive report on the biology, distribution, destructive propensities and control of this species. The main change in control recommendations in recent years is the substitution, for cogent reasons, of sodium fluosilicate for sodium arsenite as the toxic element in poison bait prepared from finely chopped hay. This bait has been proved very economical and highly successful and has been used on a vast scale in certain areas.

M. viator in a restricted area of the Karroo appears to take the place of *H. mossambicus* in desert and semidesert areas, where it destroys the shrub as well as the grass elements of the veld. Locally it constructs a striking mound above ground, each mound representing a single colony. For this reason it has been found feasible to destroy an individual colony either by using a liquid fumigant in the mound or by spraying the vegetation of the harvesting area involved with an insecticide, such as aldrin or dieldrin. The practical economy of this approach to control remains to be finally determined. It offers a logical alternative to baiting, however, because the natural cover in these areas does not provide bait in practical quantities.

Lucerne flea—*Sminthurus viridis* (L.)

S. viridis as a pest on lucerne appears to be spreading. In certain quarters a plea for the eradication of the species has been mooted. To date excellent local control has been effected by spraying with malathion emulsion.

Lucerne Beetle—*Graphognathus leucoloma* (Boh.)

The application of soil insecticides—aldrin, dieldrin, chlordane and DDT—has been proved to give effective control of *G. leucoloma* on lucerne. Up to date single applications have remained effective for two and a half years.

Other Pests

Other pests are the Snouted Haymaker, *Trinervitermes havilandi* Fuller and the grain pest, *Blissus* (*Ischnodemus*) *diplopterus* Dist. Low volume spraying with parathion or dieldrin has been shown to give effective control of the latter pest.

MAIN PESTS OF DECIDUOUS FRUIT

Codling Moth—*Cydia pomonella* (L.)

C. pomonella is showing mounting resistance to DDT treatment, evidenced by the fact that whereas four sprays per season gave good control initially ten sprays are now hardly adequate. Initially the first spray gave adequate protection for 21 days; at present infestation is becoming evident from 10 days onwards. More than 20 alternative formulations have been tested and a combination of DDT (0·1 per cent.) and parathion (0·25 per cent.) is now the standard effective recommendation. Amongst the alternative insecticide choices, both Gusathion and Sevin have been shown to be effective with no appreciable difference in actual result at concentrations of 1 to 2 lb. per 100 gal.

Woolly Aphis—*Eriosoma lanigerum* (Hsm.)

Amongst winter spray tests an emulsifiable oil, applied at 4 per cent. concentration with lindane added at the rate of 1 per cent. has given a high degree of control of *E. lanigerum*. Metasystox has given the best results of the 10 summer sprays tested.

Fruitflies—*Ceratitis capitata* (Wied.) **and** *Pterandrus rosa* (Karsch.)

The basic method of control of fruitflies that has been adopted is the use of an application of poison bait with malathion as the active ingredient. The method works convincingly under commercial orchard conditions; it is less satisfactory in urban and semi-urban areas. Both Methoxychlor and DDT have given satisfaction as coversprays. Dieldrin applied at the rate of 0·2 gr. actual insecticide per square yard shows promise as a soil poison against larvae and freshly emerged adults.

Pear and Grape Mealybug—*Planococcus citri* (Risso)

Insecticidal control of *P. citri* is at present largely effected by application of parathion sprays in spring. A change-over towards natural control is, however, gaining ground steadily depending on the local abundance of coccinellid predators and hymenopterous parasites and the control of *Iridomyrmex humilis* (Mayr.). In the latter connection marked progress has been achieved, especially through the use of dieldrin as a soil poison, the insecticide retaining its potency for over five years.

Red Spider—*Tetranychus telarius* (L.)

T. telarius has been showing increasing resistance to organophosphate insecticides. Kelthane and Dimite alone, of 14 odd insecticides tried in orchard spraying, gave satisfactory control.

Brown Mite—*Bryobia praetiosa* Koch.

On pomaceous fruits, *B. praetiosa* is largely controlled automatically through the intensive use of DDT and parathion against *C. pomonella*, as summer sprays. On peaches the substitution of copper sprays for lime-sulphur in winter sprays has necessitated the use of

Ovotran, which proved to be a better winter ovicide than lime-sulphur. As a summer spray Metasystox was the best of the 12 sprays tried; Kelthane, chlorobenzilate, Dimite, Tedion and Ovotran were unsatisfactory.

Fruit-sucking Moths—*Serrodes partita* (F.) (*inara* (Cram.))

Of 10 species of fruit-sucking moths damaging particularly stone-fruits, in the Langkloof area, *S. inara* has been shown to be responsible for 80 per cent. of the loss. Bionomic aspects remain to be elucidated before progress in control measures can be hoped for.

Leafroller—*Tortrix capensana* (Wlk.)

T. capensana, as a serious pest in pome orchards, is a recent phenomenon. Various weed species growing under a policy of non-cultivation are responsible. As an orchard spray DDT is relatively ineffective but DDD wettable powder gives good control.

Other Pests

Pernicious scale, *Quadraspidiotus perniciosus* (Comst.); greedy scale, *Hemiberlesia rapax* (Comst.) and pear budmite, *Eriophyes pyri* (Pgst.) are other pests of deciduous fruit.

INSECTS AFFECTING VEGETABLES AND FLOWERS

The following control recommendations apply to some of the main pests of vegetables and flowers.

Cucurbit flies—*Dacus ciliatus* Lw. and *D. vertebratus* Bez.—weekly applications of sweetened bait with malathion as the active ingredient; cucurbit mite—*Aculus* (*Vastates*) *lycopersici* (Massee)—sulphur dusts and sprays; red spider—*Tetranychus telarius* (L.)—Metasystox, malathion or Kelthane; cabbage moth—*Plutella maculipennis* (Curt.)—DDT up to head formation stage or malathion up to 7 days before harvesting; C.M.R. Beetle—*Mylabris oculata* (Thnb.)—malathion; Bagrada Bug—*Bagrada hilaris* (Burm.)—BHC or DDT; onion thrips—*Thrips tabaci* Lind.—DDT; Carnation Budworm—*Epichorista ionephela* (Meyr.)—Dipterex or parathion; Aphids—Metasystox or malathion up to 21 days and 7 days before harvesting respectively.

Other pests are the common cutworm, *Agrotis* (*Euxoa*) *segetum* (Schiffs.); Cape cutworm, *E. subalba* (Wlk.); budworm, *Heliothis armigera* (Hb.); Gladiolus thrips, *Taeniothrips simplex* (Morison); and the Gladiolus fly, *Epimadiza hista* Mall.

INSECTS AFFECTING CITRUS AND SUBTROPICAL FRUITS

Red Scale—*Aonidiella aurantii* (Mask.)

Parathion plus oil was the basic control recommendation against *A. aurantii* after fumigation was dropped. Amongst the apparent results of this practice is the increased incidence of *Coccus hesperidum* L. and the appearance of new pests, such as the citrus looper *Boarmia selenaria reciprocaria* (Wlk.). Effective combination sprays have been found in parathion and malathion and malathion and gusathion.

Soft Brown Scale—*Coccus hesperidum* L.

The main insecticides advocated for the control of *C. hesperidum* are either malathion or mixtures of malathion and parathion or parathion and Gusathion.

The incidence of this species is, however, also bound up with the prevalence of ant species in many orchards, notably *Pheidole megacephala* (F.) and *Anaplolepis custodiens* (F. Sm.) which interfere with the natural enemy complex. Dieldrin and aldrin are being used effectively to control these ants. As a result of boomerang problems arising out of the wide use of parathion against scale insects in citrus, special attention is at present being actively given to the possibility of strengthening the natural enemy complex, by the introduction of parasites, particularly of red scale, not occurring in the country.

Other Pests

Citrus red mite, *Panonychus* (*Paratetranychus*) *citri* (McG.), is controlled by the use of Systox, Metasystox, Tedion V., Kelthane and Gusathion. The citrus grey mite, *Calacarus* *citrifolii* Keifer, by the use of lime sulphur and Kelthane; the citrus looper, *Boarmia selenaria reciprocaria* (Wlk.), with DDT and the citrus thrips, *Scirtothrips aurantii* Faure, with dieldrin. Other pests are the circular purple scale, *Chrysomphalus dictyospermi* (Morg.), the citrus mealybug, *Planococcus citri* (Risso), the citrus bud mite, *Aceria sheldoni* (Ewing), the false codling moth, *Argyroploce leucotreta* Meyr., the Mediterranean fruit fly, *Ceratitis capitata* (Wied.) and the Natal fruit fly, *Ceratitis* (*Pterandrus*) *rosa* (Karsch).

MAIN PESTS AFFECTING FOREST TREES AND TIMBER

Eucalyptus Snout Beetle—*Gonipterus scutellatus* Gylh.

Broadly, biological control of *G. scutellatus* brought about by the introduction of the egg parasite *Anaphoidea nitens* Gir. in 1925, remains effective. Susceptible species of eucalyptus enjoy complete commercial protection over approximately 75 per cent. of the plantings. Over the remaining 25 per cent. material improvement of the situation is inhibited, either by a long cold dry season, which slows up the spring increase of the parasite or by lack of favourable tree growth, due to the fact that plantings were established on inferior sites.

Pine Brown Tail Moth—*Euproctis terminalis* Wlk.

E. terminalis is an indigenous insect which has shown predilection for certain exotic coniferous species. Damage is confined to highveld plantings where natural control fails to function adequately. The situation has been elucidated by a detailed biological and economic study (Grobler, 1956). The indigenous parasites *Telenomus phegeus* Nixon, *Meteorus trilineatus* Cam., *Tachina fallax* Mg., *Pimpla bicolor* Brullé, were studied in detail and *Compsilura concinnata* (Mg.), was introduced and established without any marked effect in the earlier stages. In the problem areas it was found necessary to devise positive control measures. A wide range of insecticides was tested against the various larval instars. Eventually the use of DDT or toxaphene applied in aerial spraying emerged as the highly effective final control recommendation, DDT being used either in emulsion or in oil soluble form.

Nudaurelia spp. **as pine defoliators**

Taxonomic studies suggest the existence of two separate species. For the present the subspecies *N. cytherea capensis* (Cram.) stands for the southern and *N. cytherea cytherea* (F.) for the Northern form. The eupelmid egg parasite *Mesocomys pulchriceps* Cam. exerts an important influence on the populations of both forms.

Natural control is, however, often inadequate and in recent years more frequently so. For many years domestic pigs were used very successfully in biological control of the pest as destroyers of the pupae. The advent of potent insecticides in recent years has, however, led to experiments in aerial spraying. These have been highly successful. Endrin as an emulsion or dissolved in diesoline has now become the standard recommendation. As the parasite is protected in the eggs of the host for a resting period extending over one year, it is not adversely affected by insecticides applied against the larva and survives to deal with the eggs of surviving moths, thereby apparently serving to prevent a notable building up of the population for several years after aerial spraying.

Thrips—*Heliothrips haemorrhoidalis* (Bché.)

H. haemorrhoidalis occurs as a sporadic but severe defoliator of exotic conifers. Aeration of the affected stand by judicious thinning serves to effect adequate control.

Wattle Bagworm—*Kotochalia junodi* (Heyl.)

K. junodi as the prime defoliator of wattle trees (*Acacia mollissima*) has for a number of years been controlled effectively by the application of aerial sprays against the larval stage. Recent work on the choice of insecticides has led to the recommendation of endrin (oil-soluble or emulsion) as the standard spray. In recent years a fresh effort has been initiated towards attaining biological control of this pest, by experimenting with suspensions of an indigenous polyhedral virus element (*Borrelina* sp.). Very encouraging results have been obtained.

Platypodid Borer—*Crossotarsus* (*Platypus*) *externedentatus* (Fairm.)

Gumming spots on the bark of growing *Eucalyptus maculata* by *P. externedentatus*, although observed for years, have only recently (1958) been shown to be due to the activity of this species. A disturbing further disclosure is the fact that this damage, occurring throughout the growth cycle, produces numerous breaks in cohesion between the successive annual layers of wood, thereby seriously lowering the structural strength of the timber. To date no remedy has been developed.

European Houseborer—*Hylotrupes bajulus* (L.)

Over the past sixteen years copious work has been done on the biology, habits and control of *H. bajulus* under South African conditions and the average life cycle proves to be much shorter locally than in Europe. The paucity of heartwood in much of the locally used coniferous timber favours the impairment of structural strength in a marked way. This threat resulted in enforcement under regulation of pretreatment of building timber and the *in situ* treatment of infested properties in defined areas, such treatments being based and prescribed on research findings. Pentachlorophenol was the main chemical prescribed for both pressure and *in situ* treatment, although *Tanalith* was found acceptable in respect of high pressure pre-treatment. Since 1955 the volume of compulsory treatment has given sufficient encouragement to justify relegating *in situ* treatment to voluntary effort. In the meantime, tests with methyl bromide as a fumigant of buildings under plastic covers has produced results, which support the use of this method as a means of eliminating infestation in buildings of a negotiable type; surface *in situ* treatment being necessary only as a deterrent to re-infestation (Tooke, 1949; Dürr, 1956).

West Indian Drywood Termite—*Cryptotermes brevis* (Wlk.)

Like *H. bajulus*, *C. brevis* came to be listed for compulsory control by pretreatment and *in situ* treatment in defined areas, the same insecticidal wood preservatives being prescribed as a result of specific toxicity work. The same concessions in regulations were made in 1955. As a result of fumigation experiments with methyl bromide under plastic covers in 1956, the method stands recommended in respect of the elimination of active infestation in buildings physically amenable to such treatment.

Oriental Termite—*Coptotermes formosanus* Shir.

The Simonstown infestation of *C. formosanus* has been known to exist since 1925. Specific investigation in recent years has shown that it persists at a comparatively low level and is apparently being kept low by marginal ecological conditions on the one hand and by *Iridomyrmex humilis* on the other. The existence of colonies in the hollow roots and trunks of living trees adds to difficulty in eradication.

Termites in Buildings

An extensive report dealing with the incidence of subterranean termites in buildings was republished in 1959 under the auspices of the National Building Research Institute of the Council for Scientific and Industrial Research—Termites, Woodboring Beetles and Fungi, Series D.R. 3 (1959). These findings which comprise recommendations on eradication soil poisoning, preconstructional treatment and pretreatment of timber have been embodied in a building code by the S.A. Bureau of Standards.

The possibilities of soil poisoning against termites are being investigated through the testing of a large range of possible termiticides in a long-range graveyard test under cover simulating buildings. The protective effect of some of the chemical agencies employed, particularly at the lower dosage levels, broke down within the first years of the test, whilst others, notably pentachlorophenol and copper napthanate—5 per cent. solutions in fuel oil at dosages of 8 gal. per 100 sq. ft. and upwards—are still giving promise of enduring effect after ten years.

Termites and Afforestation

Serious interference in the establishment of exotic plantations was investigated at the request of the Northern Rhodesia Forest Department. After a restricted preliminary survey of the basic termite fauna, graveyard tests in representative soil/vegetation types were recommended and locally implemented.

Collections around the test pegs provided material, the determination of which served to indicate the prevalence and distribution of the main faunal elements, at least on a generic basis. From this information control procedure was recommended, which advocated the elimination of the larger, fungus-feeding species by nest treatment, where dangerously abundant, and collar protection of transplants by insecticidal treatment against the smaller species, where the latter were prevalent in dangerous concentrations. As a guide to the selection of insecticides for the latter purpose, pine and eucalyptus seedlings were subjected to dipping treatment in nursery trays at Pretoria, using five products in emulsified form. Four of these containing xylol as the solvent, produced marked phytotoxic effects through the root system, the fifth, chlordane, which had a paraffin solvent, had a depressing effect only. Accordingly, chlordane emulsion was recommended for the treatment, with the wettable powder form of the several other soil insecticides as an alternative choice. It is understood that the latter choice was successfully followed.

INSECTS AFFECTING STORED PRODUCTS

Maize production occupies the premier position in so far as the growing of grain in South Africa is concerned.

Other kinds of grain such as wheat, kaffircorn, buckwheat and oilseeds are produced on a fairly big scale. All of these and their products, in addition to others, are subject to attack by the usual insects that attack stored products all over the world.

In 1954 *Trogoderma granarium* Everts (Khapra beetle) was discovered in maltings in a brewery in Natal and subsequently in a mill near Pretoria; later it was found in other places in the Transvaal. It is therefore likely that this insect has become fairly widely distributed. From latest available information the incidence of this beetle is not severe, though detailed surveys of stored grain insects are lacking.

Control Measures Against Insect Pests of Stored Products

Very intensive campaigns initiated principally by the Maize Industry Control Board have resulted in a great improvement in the insect situation in Agricultural Co-operative stores where whole maize is stored. Sanitation management has been tightened up. Stacks of grain in bags, stored in sheds and in the open, have been fumigated with methyl bromide under plastic covers at an average dose of 3 lb./1,000 cu. ft. for 24 hours.

New grain elevators have been constructed in the Transvaal and Orange Free State thus providing more accommodation for grain. Provision has been made at these new elevators to apply methyl bromide by means of a closed circuit with forced draught so that the gas can penetrate the bins evenly.

Phostoxin is now being used on a very large scale to fumigate bins of grain in elevators at inland centres and at the large elevator in Durban. Cyanogas—a very old fumigant used extensively in the United States of America and other countries—was used with great success in an old railway elevator in the Transvaal. The fumigant has many advantages over methyl bromide for use in containers which are not truly gas-tight.

While the infestation by insects of whole maize has shown a decrease, insect attack of maize products is still severe and constitutes a big problem especially in so far as exports are concerned. The problem, the solution of which lies largely in the application of existing control measures, is created by the indifference on the part of the traders concerned. The Department of Agriculture is studying the possibility of amending and extending existing legislation to enforce the control of these insects.

Fumigation of oilseeds with methyl bromide for export to Europe and United Kingdom is satisfactory but with all exports of grain and grain products the problem of re-infestations and cross-infestations occuring in ships' holds during voyages still remains. With the object of reducing these risks experimental work has been commenced on treating containers, *e.g.*, hessian bags, with insecticides. So far promising results are being obtained with one of the organo-phosphate compounds.

Experimental work has been started on the use of a harmless organo-phosphate on bulk wheat. Spray applications of malathion at a rate of 8 p.p.m. to bulk wheat in elevators have given complete protection against insects for at least 3 months. White bread, manufactured from such treated grain, is not tainted and is safe for human consumption.

Preliminary experiments with phostoxin to fumigate maize meal and bran in bags have shown that 0·5 of a tablet per bag gives 100 per cent. mortality against *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst.). The fumigation was performed under a plastic sheet. This method can possibly be used for fumigating maize products in railway wagons. The various Health Departments of the South African Railways, Municipalities and the Union Government have not reached agreement, however, on the use of certain fumigants in built-up areas and this problem must be settled before fumigants can be recommended for the disinfestation of food products in railway wagons, warehouses etc. in built-up areas.

A further test has been conducted in an open top railway truck covered with a double layer of ordinary heavy tarpaulins. Test insects—adult *S. oryzae*, *Rhizopertha dominica* (F.), *Tribolium* spp., *Oryzaephilus surinamensis* (L.)—were placed in bags of wheat, flour, bran, pollard and maize grit and Phostoxin applied at the rate of one tablet placed on the top of each bag. One hundred per cent. kills were achieved. Rats and Quelea birds in cages exposed on the top and sides of the truck throughout the exposure period suffered no apparent ill effects.

In connection with the chemical protection of bagged grain, stacked in the open air in new gasproof sheds and stores, tests were conducted on the effective life of lindane, DDT, malathion and dieldrin on various surface types. On jute bagging, malathion had the longest effective life—46 weeks—both under roof and in the open—against *S. oryzae*. Being also the safest from the point of view of toxic contamination, it has been recommended as the first choice for this purpose, lindane being the second choice. A quarter of an ounce of Pybuthrin powder plus 2 ounces of Levulite mixed with the grain gave excellent protection over 29 weeks, Levulite providing synergistic effect.

INSECTS AFFECTING ANIMALS

The Protection of Sheep against Blowfly Strike

I. The evaluation of certain organic insecticides.
II. The influence of the length of wool at the time of treatment on the duration of protection.
III. The effect of different formulations of γ benzene hexachloride (BHC).
IV. An evaluation of certain organic phosphorus compounds.
V. The duration of protection of certain insecticides under field conditions.

The above aspects of the blowfly problem as they affect the merino sheep in wool producing countries, but with special reference to South African conditions, have been investigated in the light of the protection offered to sheep treated with the newer organic insecticides (du Toit and Fiedler, 1953, 1954; Fiedler and du Toit, 1954, 1956; Stampa *et al.* 1958). An evaluation of the insecticidal properties of a large number of the chlorinated hydrocarbon compounds and thereafter of the organic phosphorus compounds was undertaken, with a view to studying their modes of action and the various factors influencing the duration of protection afforded. An " in vitro " method of arriving at an assessment of the various compounds under laboratory and semi-laboratory conditions is described, which serves as a method of screening promising insecticides prior to actual field testing. Finally, the results of an extensive field trial of four insecticides, regarded as of the greatest promise, conducted in the Karroo areas where the problem is particularly acute, are recorded. The conclusions arrived at indicate that, at present, the insecticide of choice for local application to protect sheep against crutch strike appears to be diazinon, but this is closely followed by dieldrin and aldrin, whereas BHC has proved to be disappointing due to its tendency to break down chemically when brought into contact with soiled wool in the region of the breech. The part played by what is termed " fly population pressure," defined as the sum of the accumulated strikes recorded in untreated control sheep and assumed to be indicative of the activity or incidence of blowflies, in influencing the degree of protection afforded by any insecticide, is stressed to the extent that it is believed that no true assessment of the value of an insecticide can be made without taking this factor into account.

The most recent plague cycle of the brown locust, *Locustana pardalina* (Wlk.), came to an end in 1954. Campaigns against incipient outbreaks have been undertaken most years since then, but they have all been on a small scale and no new work has been done on methods of control.

Study on Rainfall and Locust Abundance

A statistical analysis of the fluctuations in locust activity as measured by district expenditure on control measures on the one hand, and the rainfall conditions obtaining in the same districts from season to season between 1942 and 1954 on the other, indicates a definite correlation. Large increases in seasonal expenditure on locust control were generally associated with a low total rainfall for July–December during the season before. Similarly significant decreases in locust activity were found to be correlated with relatively abundant early summer rains the season before. Current early summer rainfall during years of significant increase and decrease were just as frequently rather dry as rather wet. A study of the rainfall conditions in successive seasons preceding significant increases and decreases in locust activity make it quite clear that, although dry early summers often have a depressing effect on locust activity, they nevertheless seem to be necessary in some way to initiate any significant increase in incipient swarming thereafter. The fact that locust activity is more closely related to preceding weather condition than it is to current rainfall, should make it possible to forecast a year ahead with something like 80 per cent. certainty, whether greater or lesser effort will be required to control incipient swarming in the following season, than was necessary during the campaign season just completed.

Since 1954 a study has been made of the seasonal fluctuations in average density of pre-winter adults present in each ¼° square (±250 sq. miles) of the outbreak region. Locusts at sub-swarming densities prevailing since then, have been found to fluctuate from season to season, in relation to the recorded early summer rainfall in much the same way as was found to be the case with the rate of incipient swarming. From this it seems likely that the delayed stimulating effect of a dry early summer is due to some effect on the numbers of solitary locusts rather than to direct facilitation of concentration and phase transformation. This conclusion is supported by the fact that the numbers of solitary locusts in observation plots at Middelburg, Cape, fluctuated from season to season under similar weather conditions in sympathy with the fluctuations in incipient swarming intensity within the adjacent Middelburg–Hofmeyer outbreak centre. Early studies in this area indicated that the average rate of increase of solitary populations from generation to generation prior to an outbreak is by a factor of the order of 4 per generation. At the same time it was found that the mortality per generation between hatching and the first month of adult life was of the order of 96 per cent. This, in turn, indicates that the delayed stimulating effect of dry early summers, is probably ascribable to the partial inhibition of some of the mortality factors, which normally operate against the active stages of the life cycle. The conclusion that the greater part of the mortality, through the life cycle of the brown locust occurs during the active stages, is further supported by the first results of sampling the numbers of solitary locust egg packages at the same locality at intervals through the winter and early summer. The rate of loss of egg packages was comparatively low. There was no evidence of parasitism, and only very indirect evidence of possible destruction by subterranean insects. It is supposed, by the evidence of the experimental digging up of eggs, that the reduction in numbers of egg packages noted over the four months June–September might have been caused by meerkats or other animals which had obviously been scratching holes in the ground, presumably in search of food.

Mortality Factors

While the study of the relative numbers of mainly solitary phase locusts, on a wide field scale from season to season, is giving a rough index of the effective reproductive rate of locusts in different parts of the outbreak region during an inter-plague period, some attempt is being made to determine the main mortality factors which operate to reduce the theoretical or potential numbers of descendants of ten locusts over one season, from many thousands to something of the order of 1 to 100.

Large, mobile predacious birds, like European storks, are among the most obviously important mortality factors when locust populations are not excessively large. Counts of European storks made over three summer months of 1958/59, indicated a rather constant number of 80,000 ±20,000 of these birds in the eastern, higher rainfall half of the outbreak region. Day-long observations on the rate of feeding have indicated that one stork may eat as many as 1,000 adult locusts in a day when locusts occur at a density of something like one per square yard. This rate can be stepped up by regurgitation when food is more easily obtained. However, storks seem to prefer large hoppers to adults if they have a choice. Their feeding grounds are not fixed and they are extremely efficient in locating areas in the Karoo, where locusts or grasshoppers occur at high densities. Their attentions seem normally to be limited to the eastern half of the brown locust outbreak region where stretches of open water, near which they like to roost at night, are relatively abundant.

Other obviously important predators of locust hoppers are various species of Asilidae. These have not been seen to attack hoppers in band formation, but they hunt solitary hoppers by detecting the least movement. Some idea of the abundance of these predacious flies is being obtained from regular counts of the numbers seen on fixed traverses where the numbers of locusts and grasshoppers are also regularly estimated. At certain times and places they occur in such large numbers, that one wonders how any hoppers survive. Sometimes they appear to be the dominant form of animal life and they have been seen to catch and kill one another. Like European storks, they seem to occur in larger numbers in the eastern, higher rainfall areas, than in the normally drier western districts.

Microorganisms

The obvious importance of mortality factors and the difficulty of obtaining consistent results in laboratory experiments involving the rearing of locusts, has led to the study of some of the microorganisms associated with them. Good progress has been made in the isolation and identification of a number of bacteria and fungi and one protozoan.

A chromogenic strain of *Serratia marcescens* (Bizio) has been isolated from eggs collected in the field and has proved to be pathogenic under ordinary laboratory conditions. Rapid mortality within 24 hours can be induced among caged locusts, by dipping them in a suspension of the bacterium made either from dead insects or from pure cultures of it.

Another bacterium, *Pseudomonas seruginosa* (Schroeter) Migula, seems to be commonly associated with locusts. It has been isolated from the digestive tracts of apparently healthy locusts and also from the surface of eggs. It has also been isolated from rotting eggs, abnormal ovaria and from diseased nymphs and adults. Normally healthy nymphs and adults die within a matter of one or several days after being dipped in a pure culture of this organism.

The fungus *Aspergillus parasiticus* (Speare) causes sporadic infestations and mortality amongst caged locusts. The characteristic of this disease is a darkening of the thoracic sternites. The fungus has been experimentally transmitted to both adults and nymphs.

A protozoan of the genus *Malameba* has been found infesting the Malpighian tubules of both field and laboratory material. It apparently causes a serious disturbance of the normal physiology of the host, particularly by reducing its fecundity. Heavy infestations have been found among hoppers and adults freshly collected from the field, and high mortalities have been recorded from such populations subsequently kept under observation in cages. Hoppers emerging from the eggs of infested parents rarely survive the second instar.*

Behaviour Studies

Evidence is accumulating that, in its solitary phase, the brown locust is positively anti-social. Young hoppers immediately disperse on hatching and become extremely static as careful marking and recovery experiments have indicated. Although solitary adults are occasionally seen to undertake spontaneous flights, these appear to be mainly random and extremely restricted. The average distance moved by marked females over a number of days from a given starting point is about twice that of similarly marked males. A solitary locust flushed into flight, and followed over as many as 100 successive flights, tends to circle erratically and almost invariably returns on several occasions to a few definite localities at, or close to, the original point of flushing. There is evidence that a measure of real concentration of adults occurs in recognizable food-shelter habitats, but females obviously disperse prior to egg-laying. To sum up, it is abundantly clear that, as far as the brown locust is concerned, phase transformation and swarming are usually the outcome, not of real concentration, but of virtual concentration, *sensu* Kennedy. This virtual concentration, in turn, is a result of a temporary relaxation of any of the normal population controls operating mainly against the active stages of the locusts and other Acrididae in the same environment.

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* Most of the work referred to here is due to be published shortly.

Population Dynamics and Control

The study of the population dynamics of the brown locust has not advanced much beyond the historical-geographical recording of outbreaks and, more recently, of population fluctuations at sub-swarming densities. These fluctuations in locust abundance seem to be closely related to fluctuations in the rainfall régime which exerts its effects both directly and indirectly.

In the normally dry north-western and southern districts of the outbreak region, the influence of the rainfall régime on survival of locusts is largely direct. Severe droughts of 18 months or more eventually kill locust eggs by desiccating them. Young hopper populations have been observed to be annihilated by the sudden shrivelling of the food supply when a localised thunder shower, that caused the eggs to hatch and the grass to sprout, has been followed by hot dry winds. In the central, and more especially the eastern, districts of the outbreak region, the influence of rainfall is largely indirect, and locust populations seem to be affected more by the fluctuating abundance of predators. These seem to survive in large numbers (*e.g.*, Asilidae) or penetrate more deeply in greater numbers into the locust habitat (*e.g.*, storks) during relatively wet periods. The main difficulty facing the locust control organisation in the sparsely populated semi-desert areas of the north-west Cape, is to locate the first swarms which arise very rapidly there, from quite small initial populations in restricted areas favoured by isolated thunder showers. Survival is high because natural enemies are relatively few and gregarisation may proceed relatively unhindered.

In the central part of the outbreak region, and even more so in the eastern areas, the main difficulty is to organise the control of incipient swarms on an adequate scale when they arise simultaneously and progressively over wide areas heavily infested by solitary locusts. Adaptations for desert life such as the production of extremely drought-resistant eggs on the one hand, and adaptations for evading the attention of predators in physically less exacting habitats, on the other hand, are combined in the brown locust to make it the most all-round successful species in the Karroo region of South Africa, perhaps even during inter-plague periods when it exists mainly in the solitary phase.

The short-term objective of suppressive control operations is to prevent the formation of migratory swarms, which spread the infestation from the more permanently inhabited parts of its distribution area to others that may be temporarily suitable for further rapid increase. Increasingly intensive control measures against incipient outbreaks, over the past 30 years, have effectively reduced the size and number of swarms produced. Escapes from the outbreak region practically never occur and agricultural crops now enjoy complete protection. Suppressive control has not, however, reduced the frequency with which plague conditions are initiated, nor appreciably, if at all, reduced the length of time over which plague conditions persist, in spite of sustained and expensive control operations.

BIOLOGICAL CONTROL

Biological Control of Insects and Weeds

Biological control investigations which were carried out in South Africa from 1954 to 1959 are listed below under the various pests concerned.

Loxostege frustalis (Zell.)

Although seven species of parasites had been introduced and liberated against the Karroo caterpillar in previous years, none became established in the field. Just under 6 million

Chelonus texanus Cress. were liberated without any success. Laboratory stocks of this parasite were destroyed in 1954.

Astylus atromaculatus (Blanch.)

Local investigations revealed only one indigenous natural enemy of the Spotted Maize beetle, this was an assassin bug, *Coranus sordidus* Miller. A preliminary survey for parasites of this pest was arranged by the Commonwealth Institute of Biological Control in South America but none was found.

Ceroplastes helichrysi var. *sinoiae* Hall.

The biology and natural control of the Jacaranda wax scale was studied. Jacaranda trees in the streets of Pretoria become quite white with heavy infestations of the scale, but parasites and predators always reduced peak infestations to a low level. As peak infestations were shown to occur only at intervals of several years, and caused no injury to the trees, chemical control was not recommended.

Ceroplastes brevicauda Hall.

Heavy infestations of this previously very minor pest have occurred in several orchards, undoubtedly as a result of parathion sprays. Observations indicate that parasites normally control this scale very efficiently. There are two generations per year.

Dysmicoccus brevipes (Ckll.)

A survey revealed no parasites of this pest. A predaceous moth, *Drosica abjectella* Wlk. (Tineidae), was found in the Nelspruit area. The pest was not abundant enough to justify a biological control programme.

Nezara viridula (L.)

Although reported by taxonomists from other areas of the Cape, the egg parasite *Microphanurus basalis* (Woll.) could not be found at Stellenbosch where the Pentatomid was a pest. The parasite was imported from Australia. Results are awaited.

Coccus hesperidum L.

A study was made of the natural control of *C. hesperidum* in the presence and absence of both parathion sprays and of the ant *Pheidole megacephala* (F.). About 28 different species of primary and secondary parasites were isolated from the scale. Both parathion and ants were found to increase the pest, undoubtedly by interfering with its natural enemies. The results emphasize the value of ant control and suggest that the alternate-strip method of spraying might advantageously conserve parasites.

Lucilia cuprina (Wied.) and other Sheep Blowflies

A paper was written on host selection by *Mormoniella vitripennis* (Wlk.), a parasite of blowflies (unpublished).

Helix aspersa, *Helix* (Theba) *pisana* and *Cochlicella ventricosa*

These three introduced snails are pests in the Cape Province. Two predaceous snails, *Gonaxis kibweziensis* (Preston) and *Euglandina rosea*, were introduced from Kenya and Hawaii respectively. Both species of predators are being reared in the laboratory but their value has not yet been determined in the field.

Toxoptera (*Schizaphis*) *graminum* (Rond.)

The parasite *Aphelinus nigritus* How. was introduced from Oklahoma, U.S.A., in an attempt to reduce winter and early spring infestations of the wheat Aphid. *A. nigritus* will be liberated in wheat-fields during 1960.

Icerya seychellarum (Westw.)

The Parks Department in Pietermaritzburg are concerned about heavy infestations of this pest on the Australian chestnut tree, *Castanospermum australe*, which lines the streets of the town. The scale has recently been recorded on citrus in Durban. *Cryptochaetum* *monophlebi* (Skuse) was introduced from Mauritius in 1959 but no progeny were obtained from 33 flies.

Aleurocanthus woglumi Ashby

This pest was discovered on citrus near Durban in January, 1959. *Eretmocerus serius* Silvestri was introduced from Jamaica but has not yet become established. The population of the citrus blackfly was greatly reduced by hot, dry weather during the summer of 1959–60 so that parasite importations had to be temporarily discontinued.

Hypericum perforatum L.

Chemical and mechanical control measures against St. John's Wort, which was discovered at Stellenbosch in 1942, have not succeeded in eradicating this weed. Biological control was started in 1959 by introducing *Chrysomela* (*Chrysolina*) *quadrigemina* (Suffr.) and *Chrysomela hyperici* Forst. Starvation tests, particularly on indigenous plants, have so far shown that the beetles can feed on two indigenous species of *Hypericum*.

The Utilization of Pathogenic Organisms in the Control of Insect Pests

This field of research work and its application to the control of insect pests has hardly been touched upon in South Africa. An insect pathologist is required to investigate the possibilities.

According to our records, only two pathogenic organisms have been introduced into South Africa. One, the *Coccobacillus* bacterial disease of locusts, was introduced from Mexico in 1910; as in other countries, it was of no use in the field. The other was *Bacillus thuringiensis* which gave outstanding results against *Colias electo* (L.) in the laboratory at Stellenbosch in 1951–52 but no success was reported in the field. It would be interesting to know whether *Bacillus thuringiensis* has been used successfully to any extent in other Commonwealth countries.

Very encouraging results have been obtained by Dr. L. L. J. Ossowski with an indigenous polyhedral virus disease (*Borrelina* sp.) for the biological control of the wattle bagworm, *Kotochalia junodi* (Heyl.). His experiments showed that consistently higher mortalities were obtained by using the virus obtained from remotely situated plantations, instead of using material collected in the area in which the bagworms were to be treated.

RECENT INSECTICIDAL DEVELOPMENTS AND TESTING

Today over 100 active materials are being used in the preparation of approximately 800 registered trade brand pesticides; but even this relatively large number of active materials is not sufficient because of the multitude of pests to be controlled, and the ability of certain species of pests, both household and agricultural, to acquire resistance to particular chemicals.

In general, the old-established control measures will not be dealt with here, but only the more recent developments in the chemical control of insects.

Agricultural Entomology

Although the chlorinated hydrocarbon insecticides are still extensively used against agricultural pests, there is a tendency towards the increased use of organic phosphorus materials and carbamates, particularly where resistance to insecticides is becoming apparent.

Deciduous Fruit Pests

In areas where codling moth is exhibiting resistance to DDT, DDT + parathion, Gusathion, and Sevin are recommended. For Bryobia mite control, the systemics Metasystox, Metaisosystox, Rogor 40 as well as Kelthane and Gusathion are used extensively. Tedion V–8 has given unsatisfactory control of this pest. Red spider has, in certain regions, become resistant to the organo-phosphate group of insecticides and in such cases Kelthane is giving excellent control. Tedion V–8 has proved to be disappointing against this pest. Leafroller is adequately controlled with Sevin, and against Aphids the usual systemics and Gusathion have given good control.

Citrus Pests

In addition to malathion and parathion, red scale, mussel scale and circular purple scale are adequately controlled with mixtures of parathion and malathion, and parathion and Gusathion. These mixtures are advisable where soft brown scale is a problem since they are also effective against the latter pest, whereas parathion alone is ineffective and encourages the breeding up of soft brown scale. Soft brown scale is also adequately controlled with Gusathion and Sevin.

In addition to the usual systemics, Systox and Metasystox, Tedion V–8, Kelthane and Gusathion are highly efficacious against the citrus red mite while the grey mite is adequately controlled with sulphur and with Kelthane. Gusathion is effective against Aphids while dieldrin affords good thrips control. The citrus looper is adequately controlled with DDT.

Maize Stalk Borer

Endrin as an emulsion spray and DDT in the form of granules, powder and emulsion spray are recommended for maize stalk borer control. Dipterex granules are also recommended and are highly effective. Thiodan, although not yet registered for this purpose, is showing promise.

Armyworm

Sevin and endrin are among the insecticides most recently recommended against this pest and experiments are also being carried out with *Bacillus thuringiensis*.

Fruitfly

Bait sprays containing Dipterex or malathion as active ingredients, and Staley's Sauce or dried fish solubles as the attractants, are the latest recommendations for fruitfly control. The attractants mentioned above have proved to be more attractive than sugar, although their effectiveness in this respect is not so prolonged. It has been found that serious damage may be caused to citrus if bait sprays containing malathion and Staley's Sauce are applied within three months of copper sprays.

Cutworms

Recent developments for cutworm control are the use of dieldrin, aldrin and Dipterex in bait form, mixed with mealy meal or bran. These baits are highly effective.

Wheat Aphis

Materials recently registered for use against the wheat Aphis are the systemics Ekatin, Rogor 40, Metasystox, Metaisosystox and Phosdrin. All have proved to be satisfactory.

Potato Aphis

Experiments in progress with Metasystox for the control of the Aphids causing leaf roll in potatoes, indicate that by the judicious use of this insecticide, the incidence of leaf roll may be considerably reduced in certain areas.

Castor-oil Caterpillar

WL 1650, a new chlorinated hydrocarbon insecticide, closely related to dieldrin and endrin has proved to be highly effective against the castor-oil caterpillar.

Cotton Pests

Gusathion has recently been registered for use against both the American and spiny bollworms and is giving good results.

Cockchafer Beetles

Sevin is the latest insecticide to be registered for the control of these pests.

Lucerne Caterpillar

Dipterex has proved to be most promising in recent experiments against lucerne caterpillar.

Ants

Dieldrin, chlordane and aldrin, mixed with sand, broadcast over the infested area and worked lightly into the soil, has proved very effective for ant control.

Stored-Grain Pests

The admixture of premium grade malathion emulsion to stored grain at the rate of 1 pint in 2–5 gal. water per 1,000 bushels has been approved for the protection of stored grain.

Citrus Spraying in Relation to Honeybees

In order to protect citrus from insect damage, orchards are often sprayed during the blossoming period with adverse effects on pollinating insects, especially honeybees. Experiments have shown that the incorporation of oil into spray formulations containing parathion and malathion, results in decreased toxicity of the insecticide deposits and residues to honeybees, although chemical analyses indicate longer residuality. A possible explanation is that the oil forms a protective layer over the insecticides, which results in decreased oxidation and hydrolysis of the insecticides, while at the same time offering some protection to honeybees coming into contact with the treated surfaces. The degree of reduction in toxicity to honeybees and the effect of temperature and humidity on the insecticide deposits are being further investigated.

Agricultural Zoology

Stored Grain and Other Stored Products

An important development in recent years has been the availability of coumarol products for combating rodents. These products are finding rapidly increasing use as baits both in the dry and the liquid form—*i.e.*, for poisoning the water used by rodents. They are proving very valuable as a safe and effective means of preventing the building up of infestations and eliminating existing ones.

Field Crops

For rodents of the *Tatera* group, which do extensive damage to maize and other crops in the field, grain bait poisoned with strychnine (hydrochloride) remains the basic remedy. Coumarol dusting powder has been found useful as a contact poison in the burrows as a final knockout treatment but has been replaced by 5 per cent. parathion powder which is highly efficient, almost immediate in action, and only about one-sixth of the price of the Coumarol product.

For granivorous birds of the *Quelea* group, parathion at 0·2 per cent. concentration has replaced strychnine in baiting procedure, proving much safer, more humane and rapidly effective. For destroying mass concentrations of these birds in roosts a heatblast method was developed in which a 50/50 mixture of petrol and diesoline was exploded with the aid of gelignite and an instantaneous fuse. This method was highly effective but was replaced by the use of a contact poison (parathion) applied to the roost from aeroplanes at night using 25 per cent. parathion in diesoline at the rate of 6 gal. per acre. This method gives a most effective kill, is convenient and much cheaper than the blast, and has the advantage of extreme mobility.

Porcupines in the aggregate cause very considerable damage to maize and vegetable crops. Phosphine gas applied to the burrows through the medium of tablets of aluminium phosphide has been found to offer a very cheap and convenient means of control.

Afforestation

Rodents of the *Otomys* and *Rhabdomys* group cause severe damage to coniferous transplants in the Union. As the culmination of a wide range of measures tried, baiting with Coumarol as the active agent in various carriers is yielding satisfactory results.

Household Pests

There is a general trend towards the use of organic phosphorus insecticides such as malathion, Dipterex, Korlan and diazinon for housefly control. Pyrethrum is also being used extensively for this purpose. Dieldrin is being used on a large scale for cockroach, mosquito, ant, clothes moth and bedbug control either as a residual spot spray or as a lacquer, while malathion is also highly efficacious against bedbugs, cockroaches and mosquitoes.

Insect Resistance to Insecticides

It has been established that in certain regions of South Africa codling moth has become resistant to DDT and in such areas Sevin, Gusathion or DDT+parathion are recommended.

Surveys and insect resistance studies which are being carried out to determine the degree of resistance to insecticides of houseflies, have shown that these insects, in most areas, show marked resistance to DDT and to a lesser extent to lindane. These resistant strains are, however, still highly susceptible to the organic phosphorus compounds such as malathion and Dipterex and also to pyrethrum, which can all be used successfully.

There are indications that bedbugs in certain areas are tolerating DDT; they are, however, susceptible to the organic phosphorus insecticides.

Insecticide Registration

In view of possible operational and food contamination hazards associated with the use of insecticides, and in order to protect the public against misuse and to educate them on safe and correct methods of application, the Department of Agriculture has introduced legislation whereby all agricultural remedies must be registered with them and approved by the Department before they may be offered for sale. One hundred and twenty-five firms have registered 800 insecticides.

Insecticide Application

Much excellent work on control measures fails owing to faulty methods of application. Equipment for applying insecticides to field crops varies from primitive hand-dusters and sprayers to power-operated ground spraying and dusting machinery and aircraft. In general, the trend in South Africa is away from dusting or high-volume spray application, low-volume spraying being the most favoured at the rate of approximately 20 gal. per acre. The actual effective gallonage per acre depends, of course, on the type of equipment used and on the crop to which it is applied. In view of the large areas often requiring insecticide treatment, application by aircraft is becoming increasingly popular in this country, the usual rate of application being in the region of 3 gal. per acre.

PROGRESS IN RESEARCH ON TERMITES

During the period reviewed the lines of research outlined below were given detailed attention.

The Hodotermitid Harvester Termite Problem

A detailed report of these investigations is given by Coaton (1958). The following are a few of the highlights contained therein.

The distribution areas of the two local species are charted. *Microhodotermes viator* (Latr.), which has a single hive per colony, and the food requirements of which are comparatively low, has been shown to be a desert species peculiarly adapted to the karroid and desert regions of the Cape Province and South West Africa. Its spread to the north is held in check by the northern species, *Hodotermes mossambicus*, a voracious grass-feeder, which is better adapted to survival in grassveld and bushveld savanna owing to the fact that it has developed a multi-hived nest system which expands and contracts in relation to alternating periods of scarcity and abundance of food materials.

It has been shown that pastoral practices resulting in denudation of the veld during the swarming season lead to a progressive increase of colony density of Hodotermitid Harvesters per unit area. Due to poor systems of veld management in the past over vast areas of the Union, saturated populations of these insects have developed, and there the termites are able to consume each year the total hay crop before the summer rains commence. On account of such infestations, stock-carrying capacity has been reduced, erosion has been facilitated, and it has been shown that they play a considerable part in speeding the encroachment of Karroo and desert in northerly and easterly directions into the savanna regions of the Union. Where such peak infestations exist it has been shown by experiment that erosion will be arrested, vegetal cover restored, and the march of the Karroo arrested and reversed only if improved pastoral management is preceded by control of the termites.

Much attention has been given to the development of streamlined, economically practical methods of producing and applying sodium fluosilicate-grass bait for field-scale use in the grassveld and bushveld savanna regions. The success attending these endeavours is evidenced by the fact that in the Native Trust Territories of Zululand field-scale termite control is now applied as an integral part of the soil reclamation campaign, and up to 100,000 acres have been baited successfully in a single year.

In karroid areas, where hay for bait cannot be made locally, the use of prepared bait becomes uneconomical, and experiments have been conducted in recent years to discover alternative control measures. Preliminary experiments in which insecticidal sprays have been applied directly to standing vegetation on the infested areas have been conducted. Dieldrex 15, diluted with water at a rate of 400 cc. to 44 gal. has been applied with 100 per cent. success at a dosage of 22 gal. per acre. The cost in chemicals alone is 2/6 per acre which is still too high to be practical, but further experiments to determine the minimum effective dosage are projected for the future. In those limited areas of the Karroo where contrary to normal, prominent conical clay mounds arise over the hives of *M. viator* due to the peculiar soil conditions there prevailing, Aldinel diluted with water in a ratio of 1 : 4 (v/v) can be applied with success by injection through the mounds into the hives at a cost in chemicals of only 2·5 pence per colony.

Control of the Exotic *Coptotermes formosanus* Shir.

This exotic termite was first discovered in Simonstown in 1924, and between then and 1927 spread from the West Naval Dockyard, the point of introduction, up into the town above it in a belt half a mile wide. Between 1927 and 1949 no further infestations were recorded and it was assumed that the introduction had petered out. However, in 1949 a new infestation in the dockyard was discovered and thereafter intermittent surveys carried out by the staff of the Rosebank Entomological Station revealed further active foci, both in the dockyard and the town above it.

In 1955 a permanently staffed station was established at Simonstown to establish how far the species had spread, to trace the nesting sites of active colonies and control these in an attempt to eradicate the species, and if not, to limit the chances of its spread. Regular surveys of dead wood in extra- and intra-mural habitats, to discover past and present sites of infestation, have been conducted since then; by severing roots, nesting sites within the trunks of living *Eucalyptus* and oak trees have been uncovered and the colonies controlled; approximately 200 massive *Eucalyptus* trap-billets have been buried in the soil throughout Simonstown to serve as indicators of active foci; light traps have been in use in Simonstown from spring to autumn each year to reveal the presence of colonies strong enough to swarm.

Since 1955, by such means, 8 well-established colonies have been traced and dealt with. All of these have been sited in the heartwood of trunks of living *Eucalyptus* trees. That the project is by no means ended yet is shown by the fact that alates were taken from three adjacent light traps on the 22nd December, 1959. The search for the nest of the colony from which swarming originated continues.

The surveys conducted during the past 5 years have revealed that *C. formosanus* has not spread in Simonstown beyond the original belt 0·5 mile wide and extending from the West Naval Dockyard to the upper limits of the town above it. It is clear that, although this species can exist in Simonstown, it does not flourish there. The conditions holding it in check appear to be, (a) a temperate climate marginal for this tropical species, *e.g.*, swarming takes place there during December–January, the hottest, driest season of the year, when survival of the colonising reproductives would be lowest, and (b) attack by the exotic Argentine Ant, which moves with facility into the termites' nesting and feeding sites as soon as the outer layers of wood infested become in the least disrupted. It would also appear that this termite can exist here only in man-modified environments—since Simonstown is surrounded by virgin mountain-veld and is remote from the heavily built-up areas of the Cape Peninsula. Spread elsewhere has apparently not yet taken place.

When nests are discovered in tree-trunks by means of severing roots, methyl bromide is injected into the trunks via the open channels in the roots. In this way it is hoped that surviving pockets of insects, which could re-establish colonies, will be kept at the lowest possible level.

In 1958 a second introduction of *C. formosanus* into the Union was discovered at Komatipoort in the Eastern Transvaal lowveld, the point of introduction being most probably Lourenço Marques in Mozambique. Surveys conducted since then would indicate that the species has not yet spread from this very small town to surrounding areas, and steps are being taken to deal with the matter. Since Komatipoort has a sub-tropical climate with summer rainfall, this introduction is potentially more serious than that at Simonstown.

Termite Attack on Eucalyptus in Northern Rhodesia

The Division of Entomology has co-operated closely with the Forest Department, Northern Rhodesia, in surveying the termite fauna of the potential plantation areas of the territory, determining which of the components of the fauna are responsible for heavy losses of young *Eucalyptus* planted in the various vegetation-soil types, carrying out experiments to determine the population densities of these species in the various vegetation-soil types, testing out suitable poisons for application to the soil around the roots of young trees at the time of setting out, and suggesting improved silvicultural and control practices for decreasing the incidence of attack. This co-operation, established in 1956, has continued to date. Before these investigations had started it had been found impossible, due to termite attack, to establish *Eucalyptus* plantations in any of the vegetation-soil types of the Northern Plateau, or Copperbelt, or in the Upper Valley Highgrass Woodland of the Southern Plateau. Only at Siamambo, in southern *Isoberlinia globifora-Brachystegia* woodland, had *Eucalyptus* been established with reasonable success in the past.

Observed percentage mortality of trees was found to be caused by species of the following genera:—*Anoplotermes* 4·1 per cent.; *Microcerotermes* 3·1; *Synacanthotermes* 19·4; *Allodontermes* 15·3; *Microtermes* 16·3; *Ancistrotermes* 22·4; *Pseudacanthotermes* 1·0; *Macrotermes* 14·2 and *Odontotermes* 4·1 per cent. With the exception of species of the last three genera, which damaged the young trees almost entirely during the second and third years after planting, all the other genera operated during the first year after setting out only. The *Pseudacanthotermes*, *Macrotermes* and *Odontotermes* species, which have well-defined mounds sub-tending a concentrated nest system, can be readily controlled by direct treatment of the nests. Species of the remaining genera, which cause 80·6 per cent. of the observed tree mortality and operate exclusively during the first year after setting out, have nests which are not betrayed by surface mounds and cannot for this reason be directly controlled. To cope with such attack only two approaches for increasing protection could be suggested, namely, to increase tree vitality, and to protect the seedlings at their most vulnerable stage by poisoning the soil in which their roots are set.

To prevent attack by species of the three macrotermitinid mound-building genera it was recommended that all nests be treated with toxic smoke before the area to be planted was broken by cultivation, and before the mounds sub-tending the nests were obscured. To increase tree vitality and vigour it was recommended that (a) seedlings be transplanted from the beds into paper pots instead of boxes to avoid damaging the roots when setting out, (b) the pots to contain mineral soil with artificial fertiliser additive instead of composted nursery soil, (c) when setting out, artificial fertiliser to be added to the soil adjacent to each tree to give it the initial spurt towards early closing of canopy, and (d) before setting out, the general area to be planted should be thoroughly prepared to prevent weeds smothering the young trees or competing for the limited supplies of soil nutriment. With regard to soil poisoning it was recommended that the pots with tree transplants should be dipped in the nursery in chlordane emulsion, or wettable powder suspensions in water of either dieldrin or aldrin.

These recommendations have been put into practice recently on trial plots at Ndola on the copperbelt, and at Magoye on the Southern Plateau, where *Eucalyptus* plantings have repeatedly been wiped out by termites in the past, with outstandingly successful results. Losses in these trials have been negligible and canopy is now closing.

Survey of the Isopteran Fauna of the Union, and Taxonomy

In 1956 the National Survey of the Isoptera of the Union was instituted. An index showing when alates of the various genera may be found in the nests in the various climatic regions of the Union has been compiled and is kept up to date from year to year. Survey expeditions are planned and timed so as to enable the collection of complete nest series. The objective is to obtain such series of all species from every district of the Union. All this material is accessioned into the National Collection of Isoptera in Pretoria, and in the course of time it will be studied genus by genus, new genera and species will be described, species already named will be redescribed so as to include the limits of intra-specific variation and the distribution of the species will be delimited and correlated with ecological factors.

As a result of the National Survey, the Pretoria collection is being augmented at a rate of from 800 to 1,000 Union accessions each year. The highlight thus far has been the discovery of a new Amitermitine genus from the mountains of the Southern Cape Province which, like *Anoplotermes* and *Speculitermes*, has lost the soldier caste. Numerous new manuscript species have been collected and await description.

The National Collection of Isoptera in Pretoria has been built on the foundation laid by the late Dr. Claude Fuller. His collection, which consisted of 1,378 accessions of which approximately 50 per cent. had been specifically determined, has been added to since 1936 by collections made in the Union in particular and Southern Africa in general, also by reciprocal exchange of determined material between the Division of Entomology and overseas institutions. At present the collection stands at 8,513 accessions of which approximately 3,000 have been determined to the species. An attempt has been made to obtain as complete a collection of Ethiopian species as possible, but the fauna of the other regions is represented to some extent as well.

The collection at present contains 150 genera and 807 species, and 463 primary type series are present therein. With this reference collection, taxonomic studies in the Union should be immensely facilitated in future.

As a result of the recent reorganisation of the Department of Agricultural Technical Services in the Union, economic research in the Isopteran field will be the responsibility of the entomological staff of the various agricultural regions into which the Union has been divided. As from 1960, termite research conducted by the Division of Entomology will be mainly directed towards basic taxonomic and ecological studies. Accelerated advances in this field may thus be expected in future.

TAXONOMY AND INSECT IDENTIFICATION

Basically the Division of Entomology is a local clearing house for insect determinations. It is in a position to deal fairly exhaustively with termites, thrips, fruitflies, *Protostrophus*, economic coccids, weevils and mites through its own staff and with Lepidoptera, Coleoptera and Aphidae through local liaison. A modest start has been made towards encouraging active local work on Orthoptera, Parasitic Hymenoptera and ants.

PLANT CONTROL AND QUARANTINE

Departmental reorganisation during 1954 led to the creation of the Division of Plant Control and Quarantine to handle matters previously under the control of the Divisions of Entomology, Plant Pathology and Soil Conservation and Extension.

The co-ordination of services rendered by the aforementioned Divisions and expansion of these services necessitated the enlargement of inspection staff which now total four Professional and fifty-four Technical Officers.

Duties Performed by the Division

Inspections at Ports of Entry

The expansion of imports and development of air travel necessitated the creation of inspection services at Lourenço Marques and Jan Smuts and D. F. Malan Airports, apart from the services previously maintained at Cape Town, Port Elizabeth, East London, Durban, Johannesburg and Pretoria. These services aim at the exclusion of dangerous diseases and pests—especially those which do not occur in the Union.

Quarantine

In furtherance of the aims set out above and to eliminate the introduction of certain diseases, mainly virus, a quarantine station has been in operation at Stellenbosch since 1955. This station now maintains a series of virus-free rootstocks intended for indexing purposes.

Nursery Inspection

Approximately 800 nurseries are registered with the Division annually and stocks are inspected both during the growing and the dormant seasons for insects and diseases affecting any part of the plant.

Parent tree selection for freedom from all diseases, and viruses in particular, as well as pomological requirements now form part of nursery inspection.

Special Inspection and Suppression Services

Potato Inspections—Both field and tuber inspections are undertaken in respect of potato crops grown in certain selected areas. Special attention is devoted to such matters as freedom of parent plants and tubers from virus, fungus and bacterial diseases and nematodes. " Seed " passed by the inspection service qualifies as " Government Certified."

Sugar Cane—All varieties imported are subject to quarantine for the elimination of diseases which may be introduced. Thereafter these varieties are planted in open quarantine to assess their immunity or resistance to diseases which are already present in the Union, *e.g.*, mosaic. Only highly resistant varieties are released for commercial planting and the planting of varieties not officially released by the Department is prohibited. Regular surveys are undertaken as a check on the general disease position in the cane belt and to enforce the prohibition regarding varieties.

Citrus surveys—Citrus canker was accidentally introduced into the Union during the second decade of this century but was fortunately eradicated. Regular surveys for any recurrence of this disease and for the presence of psorosis are undertaken.

Inspections for Certification of Flower Bulbs Destined for Export.—This young industry has progressed by leaps and bounds with some 200 million bulbs offered for certification in the past 4 years.

Potato Wart Disease.—This disease occurs in certain localised areas and strict control is exercised against the planting of any but immune varieties and the removal of plant material from such infected areas.

Bacterial Blight of Vines (Vlamsiekte).—This disease occurs on certain properties in the vinegrowing areas of the Cape Province. By the application of quarantine on such properties the spread of the disease to within and outside this area, especially through nursery stock, is inhibited.

Pernicious Scale.—The main deciduous fruit producing area in the Cape Province is hitherto free from this pest. This has been accomplished through a prohibition on the movement of nursery stock from infested areas into the free area. Furthermore, annual campaigns enforcing the compulsory eradication of the pest in certain districts which are close to the non-infested area are supervised by the Division. With these measures the spread of the pest has at least been delayed.

Insects Destroying Timber.—The following insects cause severe ravages on timber mainly along the coastal belt of the Union: *Hylotrupes bajulus* (L.), *Oxypleurus nodieri* Muls. and *Cryptotermes brevis* (Wlk.). Up to 1955, a policy of compulsory *in situ* treatment of timber on infested properties, coupled with compulsory chemical impregnation of all timber used for the erection of new buildings within the infested areas was followed in an attempt to eradicate these pests. Since *C. brevis* attacks both sapwood and heartwood, and hardwood as well as softwood, the *in situ* treatment of timber is of questionable value, especially since heartwood and hardwood are not amenable to treatment. Since 1955 the Division has concentrated its efforts on pre-treatment of timber as a safeguard for the owner and against the spread of these pests whilst *in situ* treatment is undertaken on a voluntary basis at the request of the owner of an infested property.

Graphognathus leucoloma (Boh.).—This beetle occurs on lucerne in certain areas of the Cape Province. Regulations prohibiting the removal of lucerne hay from infested areas, except by permit, are in force.

Surveys for Diseases and Pests

Surveys in active progress at the present time being undertaken by this Division are Lucerne flea, Citrus Black Fly, Nemorensis (Forest Pest), virus diseases of stone and pomaceous fruits, and nematodes and crowngall.

Domestic Developments of Importance

(a) Improvement of all nursery material by a long-term indexing scheme whereby all vegetative propagation will consist of indexed parent material. By this means it is hoped to improve all stocks and multiply virus-free disease-free material for the three major fruit industries. To this end, the necessary technical staff and additional subsidiary quarantine facilities have been acquired to enable parent tree foundation material to be maintained for the use of the industries and the co-operation of all commercial bodies has been obtained including the Citrus Exchange (Co-op), the Deciduous Fruit Board and the Koöperatiewe Wynbouers Vereniging.

(b) Improvement of facilities for stored grain to enable insect-free material to be available for export purposes.

Interstate Issues in the International Phytosanitary Field

The Union of South Africa became a permanent member of the International Plant Protection Convention in 1951, under the F.A.O. of the United Nations. The 1951 Convention is also known as the Rome Convention. Members (Governments) of this Convention subscribe to certain obligations as set out in Articles 1 to 10. Article 3 provides for additional agreements, which may become necessary from time to time but are not binding unless the Convention so decides.

The function of the Rome Convention is international and has nothing to do with the Regional Organisation of Europe which however retains contact for the sake of the F.A.O.

Similarly, the Inter-African Phytosanitary Convention was established in 1952 and ratified by Belgium, Portugal, The Federation of the Rhodesias and Nyasaland and the Union of South Africa. This convention is concerned with the interests of these Governments in Africa south of the Sahara and applies to territories south of 20 degrees North Latitude.

The aims of the African Convention south of the Sahara are similar to those of the International Plant Control Convention except that it applies to a specific region in Africa.

To further the aims of this Convention provision is made for a permanent Commission which is obliged to meet annually to promote the interests of the territories concerned, with powers to determine procedure, collect information and make recommendations and pass resolutions. This permanent Commission met in 1955 for the first time.

The Union of South Africa is represented on this Commission which is provided with a permanent Scientific Secretary in London, appointed by the Commission, whose functions include co-ordinating operation between territories and submission of an annual report to indicate any changes recommended by the Commission, ensuring that such recommendations are carried out and putting forward any suggestions for the improvement of plant control in the Africa region.

The Southern Africa Group (neighbouring territories) operate on the assumption that no natural boundaries exist and as such the normal restrictions for the movement of plants and plant products are not in force.

Research as such does not concern the Division of Plant Control and Quarantine directly. Certain aspects of control and surveys are, however, undertaken in close co-operation with research units and specialist Divisions. Plant control is, however, dependent on research units for the technical information required to apply control and undertake the large number of surveys in progress all the time. Similar direct co-operation and exchange of information of a practical and scientific nature takes place with all neighbouring territories and overseas countries engaged in export to the Union of South Africa. Further provision in this direction for exchange of information is secured through the Scientific Secretary of the Phytosanitary Commission for Africa south of the Sahara.

The overall trend in Plant Control is towards closer co-operation by exchange of information between territories in Africa in an effort to protect African interests. The recent appearance, for instance, of Pink Bollworm of cotton near our borders, in the Sabi Valley, Southern Rhodesia, has called for the closest co-operation for our mutual benefit.

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WEST AFRICA

1. WEST AFRICAN COCOA RESEARCH INSTITUTE

Entomological work at the West African Cocoa Research Institute is concerned primarily with the ecology and control of the two major groups of insect pests on cocoa—the cocoa Mirids, *Distantiella theobroma* (Dist.) and *Sahlbergella singularis* (Hagl.), and with the mealybug vectors of cacao swollen shoot virus. But with the increased use of insecticides and the reduction of overhead shade, other pests are appearing in significant numbers and a wider ecological approach is necessary.

Mirid Control

Recent work has aimed at improvements in assessing spraying in the field and the testing of various chlorinated hydrocarbons, and other new sprays, with a view to reducing costs. Field trials are done in co-operation with the Department of Agriculture on cocoa grown by farmers in the forest; this cocoa is far from uniform. Improvements have turned on careful selection of plots (usually 3–5 acres), a pretreatment assessment of damage and a subsequent grouping so that the plots assigned to different treatments are matched with respect to degree of damage; tree density being variable, control is assessed per 1,000 trees. Mirid populations are very difficult to assess and are therefore not estimated; instead the number of trees showing new mirid damage after treatment is the criterion. But because badly attacked untreated controls often show little *new* damage (there being little canopy) an estimate of canopy regeneration is also made.

The insecticides tested have been BHC, aldrin, endrin, heptachlor and malathion. At similar dosages there has been little difference in effectiveness between aldrin and BHC (as Gammalin 20), both giving good control at 4 oz. toxicant in 5 gal. water/acre (two treatments at a 4-weekly interval every six months). Heptachlor and malathion at this dosage gave poor results; endrin was spectacularly good in its effect and later experiments at reduced dosages (endrin, ½ oz.; BHC, 1 oz., and aldrin, 2 oz. initial treatment) confirm this with effectiveness also in that order. These experiments have now been concluded.

Mealybug Control

Despite intensive research the only successful method of control of cacao swollen shoot virus disease is by destruction of affected trees; this costs Ghana about £2·5 million p.a. The most important vector in Ghana is *Pseudococcus njalensis* Laing though other mealybugs are also important in Nigeria. *P. njalensis* is attended by Pheidoline and Crematogasterine ants some of which build protective tents over mealybug colonies. Direct spraying of mealybugs with contact insecticides is thus ineffective. If, however, the ants are destroyed, the mealybugs suffer heavy mortality from parasites, predators and fungus disease, and from accumulation of honeydew.

Dieldrin (2 treatments each of 1 lb. toxicant in 20 gal. water per acre at an 8-week interval sprayed up to a height of 10 feet on all tree trunks), reduced the ant populations on a 200-acre area to 25 per cent. of the original level; a 98 per cent. reduction of mealybugs was also attained for 9 months and a 90 per cent. reduction for another 4 months. Over 2 years, incidence of swollen shoot also fell significantly especially where " contacts " were also removed. However, the disease incidence is now once again on the increase in spite of reduced vector populations; this is unexplained.

Dieldrin applied in this way is not only expensive but creates new pests (see below) and experiments now in progress aim at reducing the amount of dieldrin by more localised spray banding, and the incorporation of resins.

Following the work on Hanane (which though effective in reducing mealybugs is costly, hazardous and suspected of tainting) other systemics are being tested in the laboratory and field at WACRI, notably Rogor and Metasystox, although it is at yet too early to consider them for practical purposes.

Minor Pests

The increased use of insecticides for mirid control and the experimental control of ant and mealybug populations with dieldrin have been followed by an increased incidence of minor pests, some of which are new. Studies on their incidence and bionomics are in progress at WACRI.

The first of these pests to increase was the small miner, *Marmara* (Lepid: Gracillariidae) whose larvae cause the well-known " scribbling " on the pods and on stems of flush tissue. This has little apparent effect on the health of the tree, but harvesting is made difficult as farmers cannot tell when badly attacked pods are ripe. *Marmara* is held in check by at least three Hymenopterous parasites (2 species of *Bracon* and a species of *Ageniaspis*) and up to 70 per cent. of the larval population may be parasitised. Sprays presumably kill the parasites and allow the moth populations to increase. Work on this problem is in hand.

The larvae of *Eulophonotus myrmeleon* Feld. (Lepid.: Cossidae) bore into branches and trunks of cocoa trees; the heavy dieldrin spray used experimentally against the ant-mealybug populations has been followed by an increased incidence of this borer. The normal level of attack of about 0·6 per cent. of trees has increased to at least 20 per cent.

In the dieldrin experiment too, a totally new pest (the " black stem webber ") has arisen. This Lepidopteron (Metarbelidae) is possibly also a new species. It forms a tent of bark fragments around the branch, feeds beneath this, ringing the branch and also boring into the centre. Damage is often at the jorquette and the branch usually dies. At least 28 per cent. of trees become attacked following the dieldrin spray.

The extensive use of insecticides and the reduction of top shade to increase yields is likely to affect also the population balance of leaf-eating Lepidoptera. Surveys have shown well over 100 species on cocoa and some of these, especially *Earias biplaga* Wlk. and to a lesser extent *Anomis leona* Schaus, can cause considerable damage.

In Nigeria, though less in Ghana, Anthribid, weevil and Scolylid attack on cocoa seedlings has caused some economic damage, as many as 85 per cent. of the seedlings have been attacked by shot-hole borers. Dieldrin in urea formaldehyde lacquers has not been successful in control.

2. WEST AFRICAN COCOA RESEARCH INSTITUTE ENTOMOLOGICAL WORK AT THE NIGERIAN SUB-STATION

Experiments in Mirid Control

The efficiency of BHC emulsion in water as a spray for the control of cacao mirids is well known and has been successfully tested, and used in practice, both in Nigeria and Ghana. Undoubtedly the most efficient means of application is by motorised mist-blowing machines, but in Nigeria it was essential to investigate the possibility of obtaining efficient control, in mature cacao, by the use of simpler hand machinery. The reasons for this were two-fold: first, many thousands of farmers already possessed pneumatic knapsack sprayers, which they had purchased for use with copper fungicides for black-pod control, and secondly the size of individual farms did not warrant buying expensive machinery.

Experimental Layout

An experiment was carried out in co-operation with the Department of Agriculture, Western Region, and laid down in sixty-three plots equally divided between three localities, Owena in Ondo Province, Araromi in Southern Ibadan Province and Ilesha in Oyo Province. Each plot was approximately five acres. Seven treatments were applied, each replicated nine times, and a random distribution of treatments made within blocks of seven plots.

The criteria for plot selection were that they should have the following features in common:—

(a) the trees should show a range of mirid damage and dieback varying from trees whose canopy was intact to those where it had been completely degraded until only the main trunk was left;

(b) they should be near a permanent source of water, should be reasonably accessible, and not less than a quarter of a mile from each other.

The treatments were:—

A. 2 oz. BHC in 5 gal. water/acre applied at 4-weekly intervals from August to February using portable motor-driven mist-blowers.

B. 4 oz. BHC in 5 gal. water/acre at 4-weekly intervals applied as in A.

C. 4 oz. BHC in 5 gal. water/acre at 8-weekly intervals applied as in A.

D. 4 oz. BHC in 10 gal. of water/acre applied at 4-weekly intervals from August to February using pneumatic knapsack sprayers fitted with nozzles producing a fine mist-type spray (Mysto 000 Bray jet or 4-Oaks 93 humidifying nozzle).

E. 4 oz. BHC in 5 gal. water/acre in August and September using motor-driven mist-blowers, followed by spot-treatment of trees showing recent damage and of their contacts, using knapsack sprayers and BHC at a rate of 4 oz. in 10 gal. water.

F. 4 oz. BHC acre applied as a dust in August and September followed by spot-treatments of damaged trees and their contacts with dusts. Hand-operated dusting machines were used.

All treatments were discontinued in February, 1957.

In each of the sixty-three plots a hundred trees were selected for detailed recording and, where possible, these were subdivided into groups of twenty, one group in each of five separate categories of canopy degradation.

Spraying and Recording

The plots were visited twice each month; on the first visit pods were sprayed with a copper fungicide against black-pod disease and those Mirids on accessible parts of each of the hundred marked trees were counted, but not removed.

During the second visit of each month the plots were treated for mirid control and the following records were taken on each of the marked trees:—

1. Canopy category; as full canopy, ¾, ½, ¼ or canopy destroyed.
2. Regeneration of (a) chupons and (b) fan branches, points from 0 to 3 being awarded according to vigour of regeneration.
3. Fresh mirid damage on (a) chupons, (b) fan branches and (c) pods. Damage to chupons and fans was assessed by observing dead leaves, all such leaves being removed after each monthly assessment.
4. Recent canopy damage resulting from dieback from old cankers.
5. Other damage. Points 0 to 3 were awarded for records 3, 4 and 5 according to the severity of damage.
6. Flushing; points 0 to 3.
7. The number of pods removed at each 4-weekly harvest, these being subdivided according to the presence or absence of mirid damage. Pods removed because of rodent damage, black-pod and other defects were included in the total yield records.

Mirid Counts

Counts made only up to hand-height on mature trees have several drawbacks as a method of insect population assessment, especially, as in the case of Mirids, where one is concerned with an insect normally present at low population densities. The ratio between those Mirids which can be seen without the use of ladders and the total numbers on a tree will depend on such factors as the degree of canopy degradation, the vertical distribution of pods and of regenerating vegetative tissue. The selection of trees in each plot in five canopy categories was an attempt to equalise the initial basis upon which mirid assessments were made. Subsequent changes in the vertical distribution of feeding sites, varying with the different treatments applied and the response of individual trees to them, was beyond experimental control. It is appreciated that canopy regeneration could result in the removal of an increasing number of Mirids from the range of assessment of the recorders and that the results might thus reflect a degree of control greater than that which actually pertained. However, as is mentioned below, counts of actual insects tended to agree quite closely with damage assessment data.

Mirid counts in the control (untreated) plots showed two peaks, one in September and another in January. It is possible that the decline noted between September and December resulted from the reduction in the number of pods and that there was a consequent movement of insects into the canopy. The second peak in January may have been the result of a downward movement induced by severe harmattan conditions experienced at the New Year which, following a year of exceptionally low rainfall, caused considerable canopy damage.

The first applications of liquid insecticide were made in treatments A to E between the 30th of July and the 10th of August, 1956, but due to the late arrival of dusting machinery treatment F was not begun till 4 weeks later.

As will be seen from Table 1 the first application of all the insecticidal treatments reduced the mirid population at a time when it was increasing on the control plots and that six weeks later counts of not more than 30 Mirids per nine hundred trees were noted for treatments B, E (see September) and F (see October), whilst D was a little less effective. At the same time there were over 400 Mirids per nine hundred trees on the control plots. The rate of decline in treatments A and C was slower than for the other treatments; this was to be expected for C, which had then received only one application of insecticide.

Initial control having been established, counts on all plots receiving regular overall treatment continued to decline until no significant differences could be demonstrated between treatments. Those receiving spot treatments (E and F) in December, January and February were less effective, spot dusting being markedly so (treatment F). Nevertheless, mirid populations in these plots were very low compared with those in control plots.

TABLE I

Number of Mirids per 900 Trees

Treatment	A	B	C	D	E	F	G
July	275	312	340	273	225	212	195
August	130	140	124	143	80	320	412
September	105	27	85	40	20	80	425
October	12	20	10	17	5	30	405
November	8	5	5	0	1	28	350
December	7	5	10	5	17	40	301
January	4	2	7	3	16	76	424
February	0	0	3	3	20	47	244
March	3	1	2	3	3	37	82

Damage Assessment

Limited mirid feeding does not inevitably lead to the death of leaves on an attacked twig, and even when it does there is a time-lag between the two events: the duration of such an interval may be influenced by factors such as the age and type of tissue attacked, its degree of exposure and by prevailing climatic conditions. Hence in assessing mirid damage by the abundance of dead leaves, it was essential, in considering the effects of different treatments on canopy regeneration, to do so from assessments made up to one month after the treatment had been applied.

Data collected from assessments made in December, January and February are given in Table II and cover a period when damage to the control plots (and the cacao generally) was most intense. The records for the assessment period beginning 17th December were taken one month after the second spot-treatment with dust (F), the 3rd spot-treatment with emulsion (E) and the third of the 8-weekly overall emulsion applications (C), whilst five applications had been given in treatments A, B and D.

TABLE II

Assessment of mirid damage on chupons and fan branches

Treatment	A	B	C	D	E	F	G
17/28 December	14	8	23	11	38	100	823
14/25 January	1	3	11	4	8	68	898
11/22 February	4	0	11	0	25	107	743
Totals	19	11	45	15	71	275	2,464

The assessments confirm the conclusions drawn from mirid counts that treatment F is inferior to all others and that treatment E is somewhat less effective than are continuous overall applications.

A significant feature of these assessments is the low value found for treatment D. Damage could be seen, when present, at heights far above the range of mirid counting and one must infer that treatment with pneumatic knapsack sprayers fitted with very fine nozzles was almost as effective as with motor-driven equipment, an important point in Nigeria where thousands of farmers already possess these simpler machines.

General Comments and Conclusions

In addition to the exceptionally low rainfall and severe dry season, the year in which these records were made appeared to be abnormal in that severe mirid damage was seen only in a few areas. By the end of February the effects of the drought were so marked that many trees were festooned with dead leaves, examination showing that much of this had not originated in mirid attack. The low level of damage observed in the Western Region suggests that spot-treatments may not have had as severe a test as might be expected in bad mirid years when the chances of re-infestation of sprayed farms from adjacent unsprayed cacao would be greater.

As a result of the above trials the Department of Agriculture, Western Region, has made the following recommendations to farmers:—

(a) 3 overall applications at 4 oz. BHC in 5 gal. from August to September at 28-day intervals, using motor-powered mist-blowing machines, followed by spot-treatments until February, or

(b) 3 overall applications at 4 oz. BHC in 10 gal. at 28-day intervals, beginning in August, and using pneumatic knapsack sprayers, followed by spot-treatments.

Experiments in Shothole Borer Control

In October, 1958, two experiments were laid down, one at Akure and the other at Ibadan, to investigate the incidence and some possible methods of control of shothole borers (Scolytidae) in seedling cacao, and the effects of the borer on the plants.

At Ibadan, the insecticidal preparations used were a urea-formaldehyde lacquer containing 10 per cent. dieldrin and 4 per cent. aldrin when dry, and dieldrin emulsion at 0·5 per cent. Preliminary phytotoxicity tests showed that the lacquer was unsuitable for application to unhardened tissues, which were killed within four days; consequently applications were made only to the lower hardened portions of the stems. The effects of a single application of the lacquer was compared with monthly applications of dieldrin to the lower twelve inches of stem. Untreated control plants, as well as the treated seedlings, received no water during the course of the dry season, though they had all been liberally watered during the first fortnight after planting in October.

Shothole borer damage was first noted in mid-November and by the beginning of December 15·4 per cent. of the 480 seedlings had been attacked; this increased to 34·8 per cent. by the end of the month and by the end of March, 1959, 84·5 per cent. of the seedlings had been attacked. Fifty-two per cent. of all seedlings had died by the end of March and a further 28 per cent. were showing severe wilt, the majority of the latter having the upper portion of the stem dead. There was no detectable response to either of the insecticidal treatments.

At Akure, a further treatment of 0·5 per cent. dieldrin emulsion applied at monthly intervals to the whole plant, as opposed to the lower foot, was included. In addition, half of the plots in each of the 4 treatments received one gal. water per plant twice weekly during the dry season. As the rains continued well into December watering was not started until the middle of that month. The results on the unwatered plots were similar to those recorded at Ibadan, though both the incidence of borers and of wilting was lower, there being approximately 60 per cent. bored and 70 per cent. wilted or dead at the end of March, 1959. Borer incidence was not reduced on those plots which had been watered, but the majority of plants continued to thrive and to grow despite this, and only 2·5 per cent. of seedlings suffered from drought symptoms.

It is apparent from this, and other experiences, that the solution to shothole borer attack, principally *Xyleborus morstatti* Hgd., on seedling cacao lies in agronomic rather than insecticidal fields; economic means of guarding against drought and wilting must be sought. In the more suitable cacao growing areas seedlings often lose their susceptibility after the first year, but in more marginal regions the period during which plants may still succumb to attack may be much longer.

Studies on Cacao Mealybugs

Mealybug Populations and their Distribution

During the year of survey (1954–55), all mealybug colonies on those parts of the trees accessible from ground level were collected from 146 batches of ten trees. The trees within the batches were randomly selected within single farms or cacao plots, the batches being taken from various localities. Each mealybug colony, together with its attendant ants, was collected separately and notes taken on its position and the presence or absence of a protective " ant tent." Adults and nymphs were later counted under a low-power binocular microscope, and representatives of each mounted on slides for identification.

One thousand and two colonies were collected from 424 of the trees, the remaining 1,036 trees having no mealybugs on the parts examined. One hundred and ten colonies contained only unidentifiable nymphs and, in a further twenty-nine, the adults were so damaged by parasites as to make identification impossible.

Eighty-two mixed colonies were found, mainly of two species each, though four of them contained three species of mealybug. *Planococcus citri* (Risso) was most frequently encountered (313 pure colonies and being also present in 44 of the mixed colonies). Colonies of *Planococcus kenyae* (Le Pelley) and *Pseudococcus njalensis* Laing were each about half as common as those of *Pl. citri*.

TABLE III

Relative percentage abundance of mealybug species

Species	From ground level	Remainder of tree	Whole tree
Pl. citri	47·0	21·7	26·5
P. njalensis	4·2	31·8	26·5
Pl. kenyae	5·4	19·4	16·6
F. virgata	32·7	2·9	8·6
P. sp. nr. *proteae*	1·8	3·2	2·9
P. concavocerarii	1·2	1·8	1·7
P. bukobensis	0	2·0	1·6
Various (3 spp.)	0	0·4	0·3
Unidentifiable	7·7	17·0	15·2
Totals	100·0	100·0	100·0

Other species of mealybug encountered were *Ferrisiana virgata* (Ckll.), *Pseudococcus bukobensis* Laing, *Pseudococcus concavocerarii* James, *Pseudococcus* sp. nr. *proteae* Hall, *Pseudococcus* sp. nr. *gahani* Green, *Dysmicoccus brevipes* (Ckll.), *Heliococcus* sp. and a species belonging to an unknown genus.

To determine whether sampling to hand-height gave a true picture of the mealybug fauna, twenty-four trees were felled and examined in detail after they had been sampled from the ground in the usual way. Two hundred and seventy-one colonies containing 885 mealybugs were thus obtained, the population per tree ranging from 0 to 165. The results are summarised in Table III.

Only 19 per cent. of the total mealybug population on these trees was collected before felling, but most species could be found in collections from ground level as well as in the canopy. The average number of individuals per colony varied with the species, *e.g.*, *P. njalensis*, 7·2; *Pl. citri*, 3·3; *P.* sp. nr. *proteae*, 1·7. The average number of individuals per colony was greater (4·3) in collections to hand-height than on the rest of the tree (3·1) despite a predominance of *P. njalensis* in the canopy.

3. WEST AFRICAN INSTITUTE FOR TRYPANOSOMIASIS RESEARCH; REVIEW OF WORK CARRIED OUT BY THE ENTOMOLOGY SECTION

By A. M. Jordan
Research Entomologist

FIELD INVESTIGATIONS

Northern Nigeria

A new method of clearing against *Glossina palpalis* (R.D.) was carried out along approximately 3·75 miles of stream near Kaduna. The method was termed " Obstructive Clearing " (Nash and Steiner, 1957) and entailed the felling of the riverine vegetation forming the overhead canopy and the blocking of the stream bed with the trash in order to obstruct the line of flight of the tsetse. It was concluded that this method of clearing does result in the eradication of *G. palpalis* and that small streams remain blocked for some years. The obstructions on larger streams disintegrate within a few years and conditions again become favourable to *G. palpalis*. The cost of the method is about half that of traditional methods primarily because re-slashing, as in the case of partially cleared streams, is unnecessary.

Studies on the nocturnal resting sites of *G. palpalis* and *G. submorsitans* Newst. (McDonald, in press), in which flies marked with luminescent paint were released and then detected with a portable ultra-violet light apparatus, have shown that both species rest on leaves and twigs at night. Many trials with *G. palpalis* showed that about half the flies rest within twelve inches of the ground; Mr. McDonald has now started an experiment on the selective spraying of residual insecticide based on this finding which, if successful, would considerably reduce the cost of spraying against *G. palpalis*. Early results are encouraging.

Collections of tsetse blood meals made by Alhaji Da'u and identified by Mr. B. Weitz of the Lister Institute of Preventive Medicine have shown that about three-quarters of the *G. palpalis* feeds were from man, domestic animals and reptiles. Over half of the *G. submorsitans* feeds were from warthog (*Phacochoerus aethiopicus*).

Northern and Southern Nigeria

An experiment was carried out near Kaduna and near the W.A.I.T.R. Field Station at Ugbobigha, Benin Province, to assess the degree of contact between man and *G. palpalis* in both Northern and southern Nigeria. Flies caught at a watering place in both areas were marked and released. It was found (Page and McDonald, 1959) that in southern Nigeria very few flies remained at the watering-place for any long period, whereas in Northern Nigeria, especially in the dry season, they remained for considerably longer periods. The rarity of sleeping sickness in southern Nigeria is believed to be due, at least in part, to the absence of close man–fly contact.

Southern Nigeria

A three years study was made of a population of *G. palpalis* along a 1,900 yards stretch of stream near Ugbobigha. Analysis of fly-round results (Page, 1959a) showed that the population began to increase in March and April (the early rains) and then decreased in the following two months to a fairly low level at which it remained throughout the rest of the year. The population decrease was associated with the onset of the period of high humidity during the heavy rains when the mean saturation deficit dropped below 3 mb. It is of interest to compare this finding with work carried out in Northern Nigeria before the period of this review (Nash and Page, 1953) when it was found that, in the north, conditions were favourable for a four months' period of increase before a decrease occurred due to high humidity. Further, in southern Nigeria, *G. palpalis* is much less dependent on riverine vegetation than it is further north. These two factors probably account for the fact that populations of *G. palpalis* never reach high densities during the wet season in southern Nigeria. Thirty-four of 1,635 *G. palpalis* (2·1 per cent.) dissected were infected with trypanosomes.

Dr. Jordan dissected 2,490 female *G. palpalis* and found 985 (40 per cent.) were pregnant: in Northern Nigeria (Nash and Page, 1953) 75 per cent. of 5,545 flies were found to be pregnant. The slow breeding rate in southern Nigeria is probably a further cause of the low population densities of *G. palpalis* there.

A three years study of the savannah tsetse *G. longipalpis* Wied., was also carried out near Ugbobigha (Page, 1959b). The catches from a fly-round, using man as a bait were mainly (98·1 per cent.) of male flies and the results which follow refer only to this sex. The lowest catches were recorded in April when the evaporation rate and temperature were falling from their dry season maxima. After April the population increased and there was a minor peak in June (early rains) followed by a period of decrease, possibly because conditions became too wet, before the population reached its highest peak in November when the rains had ceased. After November there was a fall in the population as the dry season became more severe. The forest islands—with dense thicket under high shade—appeared to be the permanent habitat of *G. longipalpis*. During the dry season flies concentrated in and around the forest islands; they were very scarce in the savannah but recolonised it in the early rains.

Dissection of 4,360 male *G. longipalpis* revealed 939 (21·5 per cent.) mature infections. This species of tsetse, widespread in " derived savannah " (Keay, 1949), is therefore a major vector of trypanosomiasis and it is probably primarily due to the presence of *G. longipalpis* that Zebu cattle cannot be kept in well-watered grasslands such as those in the north of Benin Province.

Studies on four species of the *fusca* group of tsetse flies have also been carried out at Ugbobigha; some preliminary observations on this group have already been published (Page, 1959c) and more detailed investigations, extending over a period of three years, are being prepared for publication by Dr. Jordan.

G. medicorum Aust. does not occur in the main belt of high forest and is limited to forest islands and riverine forest in the savannah. *G. tabaniformis* Westw., *G. fusca* (Wlk.), and *G. nigrofusca* Newst. are inhabitants of the high forest, although *G. fusca* also occurs together with *G. medicorum*.

A bait-ox fly-round carried out in a block of forest where *G. tabaniformis* formed 82·8 per cent. of the total *fusca* group catch (*G. fusca* 16·2 per cent., *G. nigrofusca* 1·0 per cent.) has shown that this mixed population reached its maximum in the middle of the rains and then fell to a minimum during the dry season. Other experiments have shown that *G. tabaniformis* was most active in the early morning and at dusk, and that the mid-day reduction in activity was more marked in males than in females. *G. fusca* appeared to be equally active throughout the day. *G. medicorum* has been shown to be able to withstand drier conditions than the other species of the *fusca* group.

Dissections of species of the *fusca* group have shown that *G. tabaniformis* is relatively lightly infected (103 of 3,230 flies, 3·2 per cent.), whereas the other species are much more heavily infected. *G. fusca* (110 of 827 flies, 13·3 per cent.) and *G. medicorum* (20 of 132 flies, 15·2 per cent.) are probably of more economic importance as both will penetrate the savannah and potential grazing land. *G. tabaniformis* and *G. nigrofusca* (44 of 179 flies, 24·6 per cent.) are restricted to the high forest at Ugbobigha and are probably of little importance in such areas.

A large number of blood meals collected by Dr. Jordan from Ugbobigha have been identified by Mr. Weitz. *G. longipalpis* feeds largely (70 per cent. of feeds) on bushbuck (*Tragelaphus scriptus*) and both *G. tabaniformis* and *G. fusca* feed mainly on red river hog (*Potamochoerus porcus*) with porcupine (*Atherurus africanus*) as an important secondary host. Bushbuck seems to be a more important host than red river hog for *G. medicorum* and *G. nigrofusca*.

Dr. Jordan has dissected flies of the *fusca* group and collected blood meals from a number of these and other species from other areas in Nigeria and the forest belt of the Southern Cameroons. The results have provided some interesting additions to and comparisons with data obtained from Ugbobigha. Both *G. pallicera* Big. and *G. haningtoni* Newst. and Evans have been demonstrated to be infected with trypanosomes pathogenic to cattle.

LABORATORY INVESTIGATIONS

Owing to difficulties encountered in identifying species of the *fusca* group by external characters a guide was prepared (Nash and Jordan, 1959) to simplify the identification of the West African species by dissection of their genitalia. Illustrations were made of the variations which occur within each species. A new species of tsetse fly, *G. nashi* Potts (Potts, 1955), was described from material collected by the late Mr. T. Gabesin, Technical Assistant of W.A.I.T.R., in the Southern Cameroons.

Large numbers of *G. palpalis* have been kept in a fly room at Kaduna and flies periodically issued to other sections of the Institute and elsewhere for research purposes. The temperature in the fly-room is maintained as near 25°–26° C. as possible with relative humidities ranging from 75–85 per cent. A strict routine (Nash *et al.*, 1960) is followed in the fly room; flies are kept in Bruce boxes and fed on goats daily. Nash (1955) investigated the fertilisation of *G. palpalis* in captivity and concluded that for optimum fertilisation, 3-day old females should be mated with males at least 7 days old. This routine is followed in the fly room and five males are put in each Bruce box of twenty " fertilised " females: 88 per cent. of such females are in fact fertilised, compared to 96 per cent. of females collected in the field in Northern Nigeria. Jordan (1958) studied the mating behaviour of female *G. palpalis* in captivity and confirmed that mating is most frequent in females 2 and 3 days old. The behaviour of previously mated females when given the opportunity for re-mating was also examined and, from the results of experiments in the laboratory, it was suggested that a proportion of young females might be prepared to re-mate in nature, on a number of occasions, but that the desire for mating is extinguished much sooner in life in mated females than it is in virgin females.

Mr. McDonald has attempted to establish a colony of *G. submorsitans*; his results are being prepared for publication. Much has been learned of the feeding and mating requirements of this species, but high mortality among the stock of wild females, the main source of pupae for replenishing the colony during the rains, remained an unsolved problem. Extreme care in feeding and clean culture appear to be of prime importance. The flies are kept in large boxes, designed by Mr. Petana, and these have proved far superior to the Bruce box for rearing *G. submorsitans*. An experimental " self-supporting " colony, although still only in the F_4 generation is producing some interesting and encouraging results.

McDonald and Wijers (1959) devised a technique for the artificial feeding of tsetse flies by inserting a micro-pipette into the anus of a fly immobilised between two flaps of plasticine. By feeding *G. palpalis* blood infected with *Trypanosoma gambiense* Dutton, a gland infection rate of 15·8 per cent. was obtained among 82 anally fed flies. Flies infected by anal feeding transmitted the infection to a clean monkey. Mr. Petana has reversed the technique and, by withdrawing hind-gut contents of *T. gambiense*-infected *G. palpalis*, has demonstrated the presence of trypanosomes, without harming the flies.

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4. WEST AFRICAN STORED PRODUCTS RESEARCH UNIT; RESEARCH IN THE MINISTRY OF COMMERCE AND INDUSTRY, FEDERATION OF NIGERIA

This Unit is financed by the three Regional Marketing Boards and the Federal Government of Nigeria. It is responsible for most of the stored products research in Nigeria and its work programme is agreed at annual meetings of a committee made up of representatives from interested authorities. Professional advice and guidance are given by the Stored Products Sub-Committee of the Colonial Office, while close contact is kept with the Tropical Liaison Officer for food storage.

The Unit has laboratories in Lagos, Ibadan, Kano and Port Harcourt. Most of the entomological work has been carried out at Ibadan and Kano. A full summary of the work of the Unit in the last five years is given in the Annual Reports of the W.A.S.P.R. Unit for 1956, 1957, 1958 and 1959. A brief review of the entomological work is given below.

Insect Infestation on Stored Groundnuts

Groundnuts form the main agricultural export of the Northern Region of Nigeria. While stored awaiting shipment they are susceptible to attack by the beetles *Trogoderma granarium* Everts and *Tribolium castaneum* (Hbst.), and the moths *Ephestia cautella* (Wlk.), *Plodia interpunctella* (Hb.) and *Corcyra cephalonica* (Stnt.). The two species of beetles have been the most serious pests, and much work has been carried out on the effectiveness of insecticides against these insects, particularly *T. castaneum*.

T. granarium has been largely brought under control by rapid inspection followed by fumigation with methyl bromide under gas-proof sheets. This and other pest control measures are carried out by the Pest Control Section of the Northern Region Produce Inspection Service. W.A.S.P.R.U. gives advice to this Unit and initiated the pest control measures originally.

Control of *T. castaneum* is not fully achieved but routine spraying and fogging keep down the numbers. BHC as a wettable powder was found to have rather a short active life and a search for more persistent and toxic insecticides has led to the testing of diazinon, malathion and dieldrin applied on various substrates. At present malathion is the recommended insecticide because of its high kill compared with a low rate of mammalian toxicity. Observations are being made on the efficacy of the treatments, and to ensure that contamination is kept well below the limit. Dieldrin proved the most persistent of the insecticides tested, and was particularly effective on concrete compared with the other insecticides tested. However, in view of its high mammalian toxicity it has not yet been recommended.

In addition to work on insecticides, inert dusts have been tested but were not sufficiently effective at an economic cost. Airtight storage has been investigated together with sealed storage of the Ctesiphon type. Paper bags were tested and found to allow of fumigation and to prevent reinfestation but were too fragile to be of practical use for groundnuts.

The present situation regarding infestation on groundnuts is that infestation by *T. castaneum* has been brought to very low levels in Nigeria but that concurrently with the decrease in *Tribolium* there has been an increase in the numbers of the moths *P. interpunctella, E. cautella* and *C. cephalonica*. This problem is being investigated.

Infestation on Cocoa Beans

Infestation on cocoa beans is not normally at a high level but on this valuable product it is desired to keep infestation at a minimum. The main pests are *Lasioderma serricorne* (F.), *E. cautella*, *T. castaneum* and *Ahasverus advena* (Waltl.). The first two species are responsible for most of the damage to cocoa, and the second two contribute to general contamination of the commodity.

Research on methods of control centred at first on studying misting with synergised pyrethrins but this was found impractical because of their poor persistence. Insect control is now based on fumigation with methyl bromide under gas-proof sheets at a rate of 1 lb. to 10 tons of cocoa beans. In 1957 the Western Region Produce Inspection Division set up a Pest Control Section to carry out the fumigation of cocoa beans and other measures.

The only insecticide allowed to be used on cocoa beans is pyrethrins which, so far, have not been found sufficiently effective in protecting this commodity. W.A.S.P.R.U., therefore, has turned its attentions to physical protection of fumigated cocoa. Work has been carried out on paper bags and polythene sheets, the latter proving quite satisfactory in preventing cross infestation to uninfested cocoa. Paper bags were effective in allowing fumigation and largely prevented reinfestation but were not sufficiently robust. Various types of hessian bags have been tested, but none were sufficiently better than B-twill in all respects, and the heavier, closer weaved bags did not entirely prevent the entry of insects.

In connection with the work on cocoa, tests on the effectiveness of DDT and malathion on warehouse walls against *T. castaneum* have been carried out, and showed the long persistence of DDT which lasts for up to six months in the hot and humid conditions of southern Nigeria.

Grain

Work on maize has included the testing of the susceptibility of various varieties to attacks by *Sitophilus oryzae* (L.). The better yielding varieties were often the most susceptible to attack. Maize in cribs has been protected with partial success by dusting cobs with 5 and 10, 20 and 40 p.p.m. BHC and 8 p.p.m. malathion. The different doses reduced the build-up of infestation to a similar extent. Both insecticides showed little persistence but initial control seemed to have a lasting effect.

Guinea Corn is susceptible to infestation by *S. oryzae* and *Rhizopertha dominica* (F.). Infestation has been successfully controlled by air-tight storage in steel drums, without impairing germination over a period of 18 months. The protection of Guinea Corn in " rhumbus " with BHC and malathion has been studied.

Legumes

Infestation of Cowpeas by Bruchids has been studied and items of work have included a study of the egg laying of *Callosobruchus maculatus* (F.) on different varieties of cowpeas and the protection of cowpeas against *C. maculatus* by dusting with DDT and inert dusts, and the use of hermetic storage. The latter was the most successful treatment. The weight loss and damage caused by insects to cowpeas during six months has also been studied.

Other work of the Unit involves the study of the chemistry of food storage and does not come under the scope of this review.

A list of papers published by the Unit and its staff follows in the references.

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WEST INDIES

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE, REGIONAL RESEARCH CENTRE

1. PESTS OF STORED PRODUCTS

By M. H. Breese

Infestibility of Stored Paddy

Surveys have shown that while peasant-produced (hand-harvested) paddy normally has a very low infestation even after long storage (12 to 15 months), paddy that has been mechanically handled often becomes quite heavily infested. Five pests are involved: *Rhizopertha dominica* (F.), *Sitophilus sasakii* (Tak.), *S. oryzae* (L.), *Sitotroga cerealella* (Ol.) and *Lophocateres pusillus* (Klug.).

The last two are of minor importance in bagged paddy; *Sitotroga* is confined to the periphery of the stacks and probably never occurs in very great numbers; *Lophocateres* is only serious when paddy has been subject to considerable attack by other pests. *Rhizopertha dominica* is undoubtedly the dominant pest. Indications are that the species of *Sitophilus* most commonly found in paddy is *S. sasakii*, whereas that in milled rice is *S. oryzae*, but since characters for the definite separation of these species have only recently been published, further survey is required to verify this.

S. sasakii is rarely able to bite through the intact husk of a paddy grain, and oviposition is therefore limited to grains having husk defects sufficiently large to allow the female to bite into the kernel. Husk defects which permit oviposition are, however, often too small to allow the adult, that has developed within the kernel, to emerge. Development of *S. sasakii* infestations in paddy is therefore slow, and the rate is often a measure of husk damage or defects. Adults of *R. dominica* may be able to bite through an intact husk, but probably do not do so much more often than *S. sasakii*. Eggs of this species are, however, laid outside the grain, and entry into the kernel is effected by the first-instar larva. It can therefore exploit much smaller husk defects than *S. sasakii*. Newly emerged adults find little difficulty in cutting their way through the husk out of the grains in which they have developed, and since only about one-third of a kernel of a normal size grain is consumed in development, emergence renders a fair amount of kernel easily accessible to other adults or newly hatched larvae. In the absence of a husk defect, the first-instar larva may gain access to the kernel of a paddy grain by boring along the rachis. This occurs more often in immature (green) paddy grains than in those that are mature when harvested. The proportion of green grains and those with damaged husks is usually directly related to the method of harvest. Both occur more frequently in combine-harvested paddy than in paddy which is hand-harvested.

The combination of a high proportion of grains with damaged husks and a high storage-water content renders combine-harvested paddy suitable for the development of high infestations of *R. dominica* and *S. sasakii*.

The Development of Cucujids in Unrefined Sugars

These studies arose out of an infestation that occurred in a raw-sugar storage experiment carried out at a Trinidad sugar factory. A general survey of factory and wholesalers' stores showed that stocks of unrefined sugars were commonly infested in small measure by three species of Cucujids, viz., *Nausibius clavicornis* (Kug.), *Oryzaephilus surinamensis* (L.) and *Oryzaephilus mercator* (Fauv.). Each of these species can complete its life history on raw or Demerara sugar and *N. clavicornis* and *O. mercator* could, under favourable conditions, maintain a low rate of multiplication. The Trinidad strain of *O. surinamensis* is, however, small and shows a low oviposition rate, and infestations of this species on sugar would generally die out. Unrefined sugar should not, however, especially in the tropics, be disregarded as source of infestation or carry-over of *Oryzaephilus* species.

2. EFFECT OF LIGHT AND FERTILISER TREATMENT ON MEALYBUG ON CACAO

By R. G. Fennah

The distribution of a population of mealybugs consisting mainly of *Planococcus citri* (Risso) was followed for two years on cacao trees of three clones grown under different degrees of light intensity and given different fertiliser treatments. It was found that under the rainfall conditions prevailing during the period of observation, the heaviest incidence of mealybugs was negatively correlated with degree of light intensity, positively correlated with the application of nitrogen, negatively correlated with that of potassium, and not correlated with that of phosphorus. Heavy incidence was negatively correlated with vigour of the host plant, and this, in turn, was negatively correlated with the depth of gravel below the soil surface. The incidence of mealybugs was also observed on rooted cacao cuttings subjected to various treatments, including starvation of single nutrient elements, administration of single nutrient elements in excessive amount, over-watering, both in the presence of free lime and otherwise, and exposure to low diurnal humidity and high temperature.

It was established that mealybugs were potentially associated with cacao plants having a high nitrogen status, and the observed differences in their abundance on plants which had received different cultural treatments could be explained as reflecting the effect of such treatments on the metabolism of the host, particularly with regard to the utilization of nitrogen.

ZANZIBAR

ENTOMOLOGICAL WORK

By A. K. Briant

Director of Agriculture

The experiment to control *Pseudotheraptus wayi* Brown by periodic spraying with a formulation of DDT was continued. The spraying machine used was the Long Ashton mist-blower which was operated and drawn by a Ferguson tractor. In this experiment the area sprayed was approximately one hundred acres and a neighbouring area of about the same size was used as a control.

About ten or twelve months after the spraying was initiated there was evidence that the yield of nuts was enhanced by the spraying and the yields obtained during the next year were possibly higher than they would normally be by some twenty per cent. In the following year, however, the number of nuts harvested was less than average. The increase in the number of nuts which was obtained in the second year of the experiment appears to have been nullified by the reduction in yield in the third year.

The research on *Pseudotheraptus* was undertaken by Dr. F. L. Vanderplank until April, 1959, after which it was taken over by the Colonial Pesticide Research Unit which has stationed an entomologist, Mr. B. H. Hyde-Wyatt, and a Field Officer in Zanzibar.

The growing of cocoa in Zanzibar is now being encouraged actively. Experiments have indicated that cocoa will only grow satisfactorily in Zanzibar if it is grown under conditions of very light or no shade. Such conditions invite attack by insects particularly *Helopeltis*, and periodic sprayings will be essential. During the early stages of growth leaf-eating beetles are extremely destructive and until the plants are three or four years old it is desirable if not essential to control these pests by spraying three or four times a year. The insects mainly concerned are species of *Systates* and a Chrysomelid beetle.

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